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ARCHIVES OF SURGERY

VOL. 9 JULY, 1924 No. 1

EXSANGUINATION-TRANSFUSION *

A NEW THERAPEUTIC MEASURE IN THE TREATMENT OF SEVERE TOXEMIAS

L. BRUCE ROBERTSON

TORONTO

The treatment of the severe toxemias accompanying many of the diseases of childhood constitutes a problem of great difficulty. In those cases in which the toxemia arises from a suppurative focus, surgical drainage, by removing the source of the toxin, usually meets the requirements of the case. But in the majority of instances, the toxemia arises from a source which cannot be attacked surgically (for example the toxemia of severe superficial burns, of erysipelas, or of acute intestinal intoxication), and in such cases the problem of treatment assumes quite a different aspect.

The method advanced in this paper for the treatment of such toxemias was suggested during the campaign of 1916 in France by observing two cases of soldiers suffering from severe carbon monoxid poisoning. They were treated by venesection, followed by blood transfusion, and made surprisingly rapid and complete recoveries. Apparently, the removal of a portion of the damaged blood had a powerful influence in bringing about a cure. The effectiveness of the treatment in these cases of gas poisoning at once suggested the idea that various other toxemias might be treated successfully in a similar manner, and as soon after the war as opportunity was afforded, the subject was investigated in a series of experiments on animals. While these experiments gave very encouraging results, it was soon recognized that in profound toxemias the employment of bloodletting followed by blood transfusion was often ineffective owing to the relatively small proportion of the total quantity of blood which was removed and replaced. This proportion is fixed by the amount of blood which can be withdrawn from such a patient before he exhibits signs of exsanguination. Attention was directed, therefore, toward finding a means whereby a greater amount of blood might be withdrawn without danger to the patient. This problem has been satisfactorily solved by combining the exsan-

* This paper was compiled from notes of the late Dr. L. Bruce Robertson by his associates on the staff of the Hospital for Sick Children, Toronto.

guination with the simultaneous transfusion of blood. By this means, it is possible to increase enormously the amount of toxic blood which can be removed without producing symptoms of blood depletion, and the effect on the toxemia is correspondingly improved. To the operation in its present form, we have given the name "Exsanguination-transfusion."

As our experience with the method has increased we have recognized that the more complete the replacement of the patient's blood with fresh blood, the more dramatic is the effect on the toxemia, and the more likely is it to be permanent. We have made it a rule, therefore, before commencing the operation, to secure a sufficient number of suitable donors to provide considerably more blood for transfusion than the total quantity known to be contained in the patient's body. Unfortunately, the necessity of replacing all or nearly all of the patient's blood with blood transfused from donors places a definite limitation on the general applicability of the method. Obviously it is practically out of the question to accomplish such results in adults. The method has been limited, therefore, with a few exceptions, to children, and usually to children under three or four years of age.

The technic of the operation is as follows: blood is withdrawn by puncture of the median basilic vein of the donor or donors into 100 c.c. glass syringes, each of which contains 10 c.c. of freshly prepared 3.5 per cent. sodium citrate solution. As each syringe is filled it is inverted several times to ensure the proper mixing of the contents, and then emptied into a basin. A quantity equal, at least, to the total circulation of the patient is thus obtained. In estimating the amount required we have been accustomed to consider that the quantity of blood in any patient's circulation is roughly 35 c.c. per pound of body weight. The desired amount having been withdrawn, it is laid aside until required at a later stage of the operation. Its temperature is maintained during this time by a water bath at a temperature of 100 degrees F.

The recipient is then prepared. The cannula for the transfusion is first tied into a suitable vein, such as the internal saphenous at the ankle, or the median basilic at the elbow, and salt solution is slowly introduced to prevent clotting. The exsanguination cannula is then inserted (Fig. 1). In small infants, the superior longitudinal sinus is made use of for the exsanguination (Fig. 2) but in children in whom the anterior fontanelle is closed the femoral vein provides a suitable substitute. The superficial veins are not satisfactory as they cannot be relied upon to yield a rapid and continuous flow of blood. When the femoral vein is used, a large cannula is introduced into it through the saphenous vein, which can readily be picked up just before it perforates the cribiform

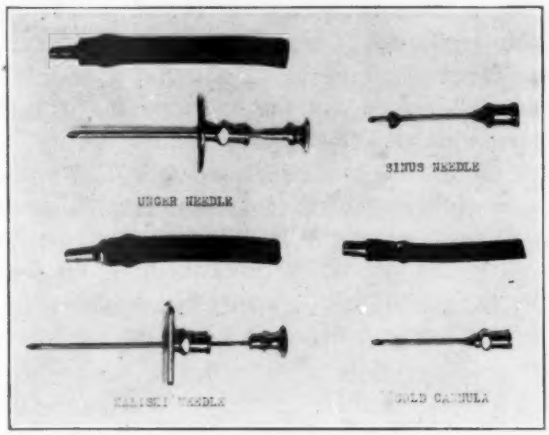

Fig. 1.—Types of cannulae used. The Unger and Kaliski needles are for puncture of the donor's vein; the sinus needle with guard is for the puncture of the superior longitudinal sinus; the gold cannula is for insertion into the recipient's vein. The rubber connecting pieces with metal adapters are to connect the cannulae with syringes.

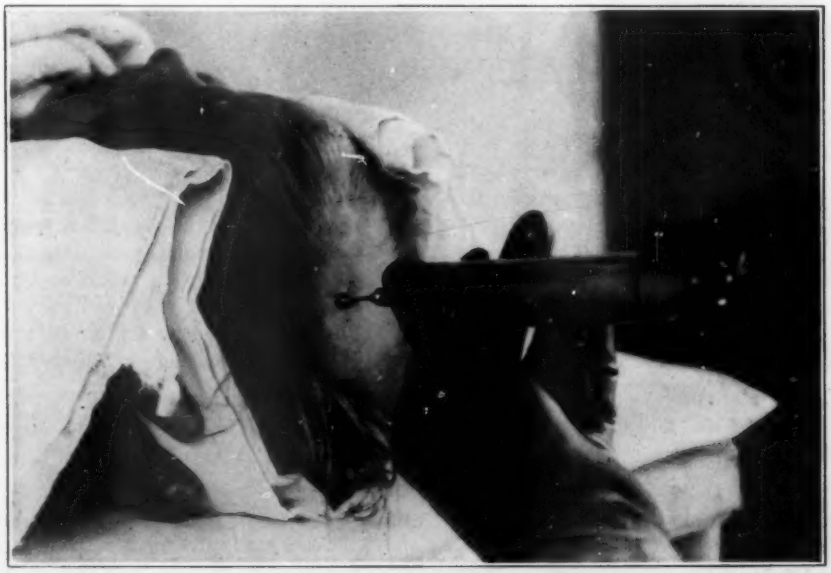

Fig. 2.—Exsanguination from the fontanelle. In infants in whom the anterior fontanelle is still open, blood can conveniently be removed from the superior longitudinal sinus by this route. The sinus is punctured by a guarded needle with a short bevel, thus providing a large and rapid stream of blood.

fascia (Fig. 3). By introducing the cannula in this way, the continuity of the femoral vein is not disturbed, and the risk of injuring the circulation of the limb is avoided.

Blood is now withdrawn from the patient until signs of exsanguination begin. The amount of blood withdrawn at this stage varies greatly, and depends entirely on the effect on the patient. We have found the amount withdrawn from small children to vary from 60 c.c. to 160 c.c. With the first sign of weakening pulse, one of the 100 c.c. syringes containing citrated blood from the donors is connected with the transfusion cannula, and the introduction of fresh blood is commenced. If it appears that the withdrawal of blood has approached too close to the margin of safety, five to ten minims (0.3 to 0.6 c.c.) of a $\frac{1}{1000}$ epinephrin solution are administered by means of a

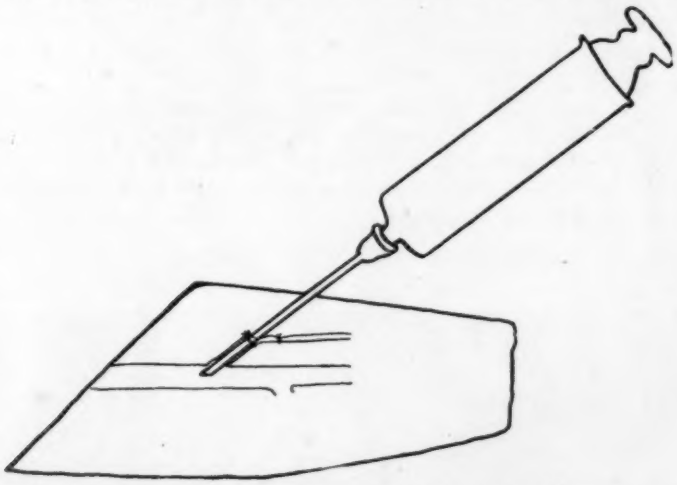

Fig. 3.—Exsanguination from the femoral vein. In children whose anterior fontanelle is closed, exsanguination can most conveniently be performed from the femoral vein. A large cannula is inserted into the saphenous vein near the point where it pierces the cribiform fascia. The cannula is pushed along the saphenous vein until it reaches the femoral. By this means, a large quantity of blood can be removed rapidly without endangering the circulation of the limb, as would be the case if the femoral vein itself were opened and ligated.

hypodermic needle thrust into the rubber tubing which connects the transfusion syringe with the cannula in the vein. After transfusion has begun, the withdrawal and the introduction of blood are carried on simultaneously at approximately the same rate until all the available blood has been transfused. As a rule, we have introduced rather more blood than was removed, the excess usually being from 100 to 150 c.c., but if, prior to operation, there were cyanosis and other signs of failing circulation, we have made it a practice to withdraw slightly more blood than the total amount injected.

The beneficial effect of this procedure in certain profound toxemias and septicemias has been demonstrated clinically on a great many occasions. In most instances, this effect has probably been produced by the simple mechanical removal of a large amount of circulating toxin or bacteria. The results in severe infections, however, have led us to believe that the introduction of fresh blood has also a beneficial effect which may be due to the addition of a fresh supply of complement and of immune bodies present in normal adult blood.

The operation of "exsanguination-transfusion" has been performed mainly in the treatment of the following conditions: (1) the toxemia of severe burns; (2) erysipelas; (3) acute intestinal intoxication; (4) resorcin poisoning; (5) malignant scarlet fever, and (6) septicemia. In all, up to February, 1922, there have been 160 operations.[1]

CONDITIONS TREATED

Toxemia of Extensive Burns.—A review of a hundred consecutive cases of burns and scalds admitted to the wards of the Hospital for Sick Children shows an appalling mortality rate. Many of the fatalities are due, of course, to the primary shock produced by the burn, and, in view of the severity of the injury in these cases, the mortality is not surprising. The majority of the patients, however, recover from the primary shock, but in the course of twenty-four hours or so develop the symptoms of an intense toxemia from which they frequently succumb. The symptoms of this toxemia are fever (often rising as high as 107 degrees) (Fig. 4), vomiting, muscular twitchings, convulsions, and circulatory collapse. In the cases that recover, the toxemia persists for four or five days and then subsides rather quickly. It is exceedingly rare, to see patients recover after the development of convulsions, and no treatment which hitherto has been employed in this hospital, with the possible exception of blood transfusion, appears to have had any influence on the condition.

In an experimental investigation of the toxemia of burns carried out by Dr. Gladys Boyd and the writer,[2] it was found that soon after the burning of living tissues and particularly after the burning of the skin, a toxic substance appears in the blood, in close combination with the red blood cells, which, when introduced into other animals produced

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1. Since this date, the operation of exsanguination-transfusion, devised by Dr. Robertson, has become an established procedure at the Hospital for Sick Children, in the treatment of burn toxemia, erysipelas, acute intestinal intoxication, and septicemia. Up to the date of writing (March, 1924), the operation has been performed on 501 occasions. The recent results are even better than those recorded in this paper.

2. Robertson, Bruce, and Boyd, Glayds, L.: J. Lab. & Clin. Med. **9**:1-14 (Oct.) 1923.

the characteristic toxemia. This toxin is definitely produced in the burned area and increases in quantity during the first thirty-six hours following the burn.

These findings, in combination with our clinical observations, have convinced us that the problem of the treatment of the toxemia of burns consists in finding a means of preventing the absorption of the toxin, or, if this is impossible, in getting rid of it after it has reached the blood. The toxemia can be prevented by the early excision of the burned area, but unfortunately, in the patients admitted to hospital, this method is rarely practicable owing to the large size of the area burned, to the situation of the burn (for example, the face), or to the establishment of toxemia before the patients are admitted. Our attention has

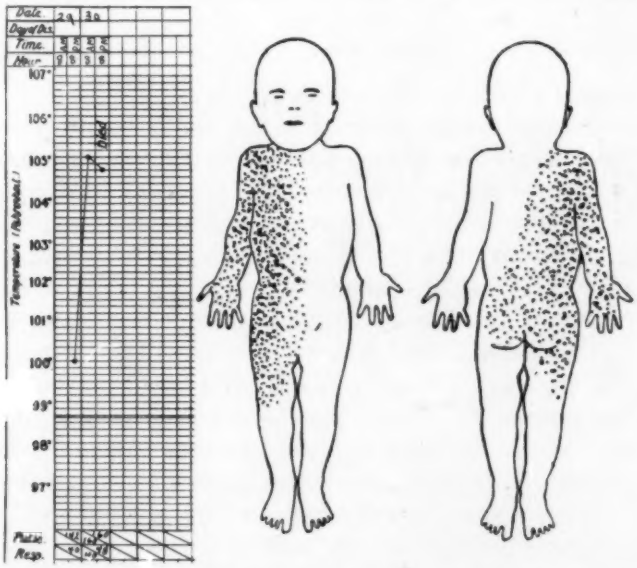

Fig. 4.—Characteristic temperature chart of a fatal burn, death being due to burn toxemia. C. S., aged 3, was admitted in shock four hours after a severe and extensive burn (see diagram). The temperature rose rapidly; the child became restless, had several convulsions, and died twenty-four hours after admission.

been directed mainly, therefore, toward combating the toxemia after it has become established and since the toxin is closely associated with the red blood cells, our efforts in this direction ultimately led to the idea of replacing the toxic blood with fresh blood and finally to "exsanguination- transfusion."

The results of the use of this method in severe burns have been very encouraging (Figs. 5 and 6). Up to February, 1922, fourteen cases had been treated by "exsanguination-transfusion." No selec-

tion of cases was observed, as it was felt that the value of the procedure could not be properly assessed if only those were chosen which seemed likely to give successful results. This group of fourteen cases was composed of all the cases of severe burns admitted over a definite period, which exhibited those symptoms of severe toxemia which our clinical experience has taught us to associate with a certainly fatal result. In eleven patients, convulsions had begun before the operation. In some of these cases, the extent of the burn was more than one third of the body surface, and, in large areas, the tissues had undergone heat coagulation down to the underlying muscles. Of these fourteen cases, seven recovered. In the opinion of all who saw the patients, the mortality

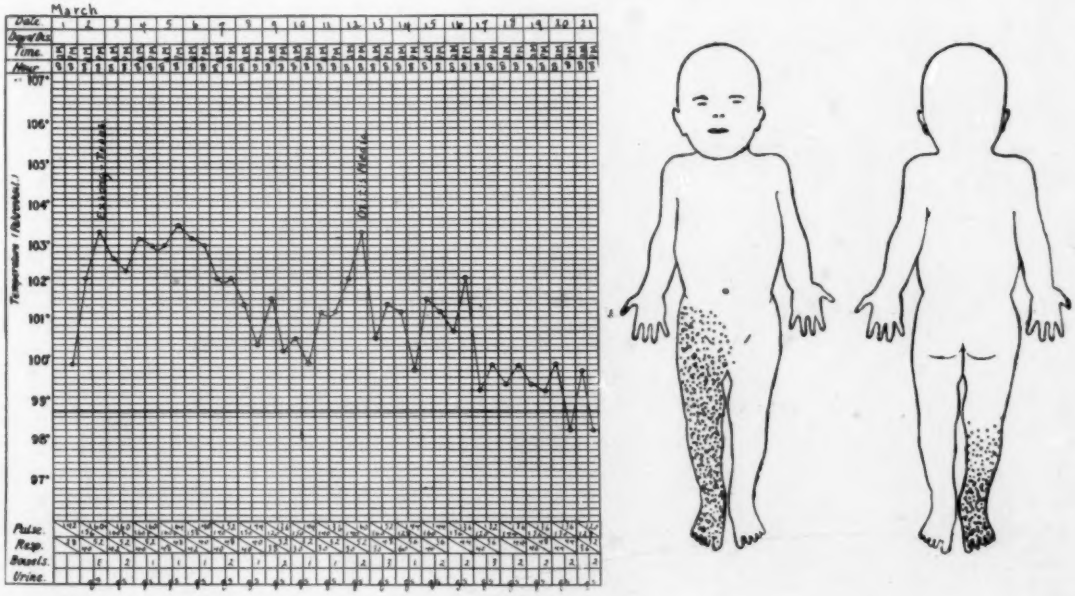

Fig. 5.—Temperature chart and drawing of a severe scald with intense toxemia, treated by exsanguination-transfusion, which was followed by recovery. P. K., aged 13 months, was admitted two hours after a severe first, second and third degree scald of the extent indicated in the diagram. A severe toxemia developed twelve hours after admission, and the child had several severe convulsions. The pulse rose to 160 and became very weak. The child was drowsy, toxic and cyanosed. Exsanguinated 300 c.c. and transfused 400 c.c. twenty-four hours after admission. One convulsion following transfusion. There was steady improvement following the transfusion, interrupted only by an elevation of temperature due to otitis media. (See Fig. 6).

would have been 100 per cent. without treatment, so that the results of exsanguination-transfusion in this series represents a reduction in mortality from approximately 100, to 50 per cent.

Of fourteen cases of toxemia resulting from burns, seven patients recovered, seven died, and the mortality was 50 per cent. All were of a severe type, such as previous experience had led us to regard as fatal. All were treated by exsanguination-transfusion after the symptoms of toxemia had developed. In eleven cases this went as far as the production of convulsions. The resultant mortality is approximately 50 per cent. lower than in untreated cases.

Erysipelas.—In searching for other conditions which might be benefited by this principle of treatment, our attention was early attracted to the statistics of erysipelas in young children. The mortality in cases

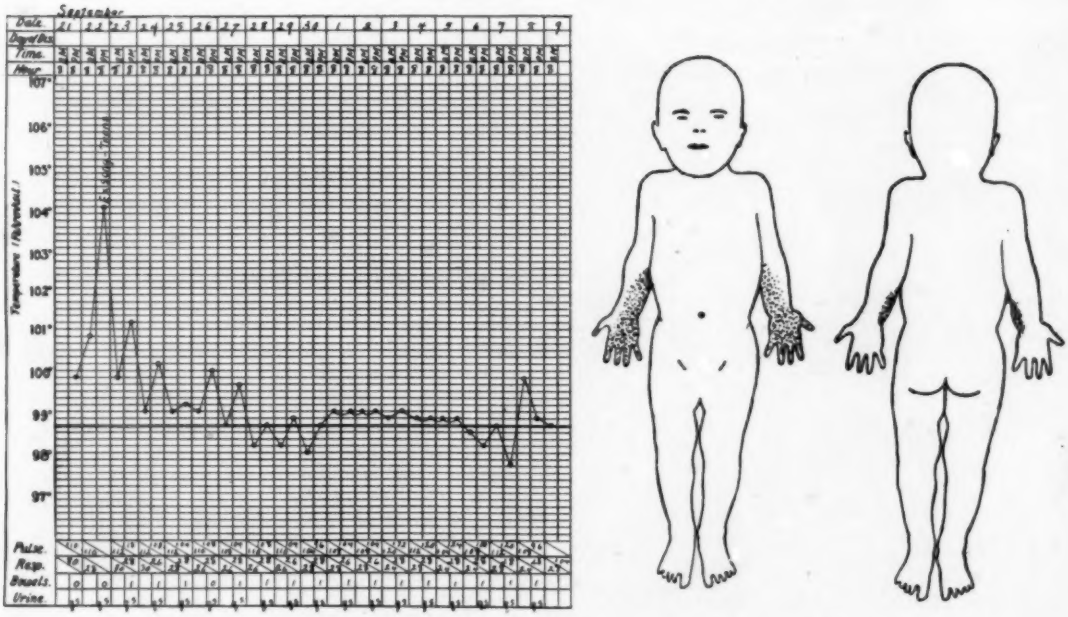

Fig. 6.—Temperature chart of a moderate severe burn with toxemia. P. F., aged 19 months, weight 18 pounds (8.1 kg.), was admitted twenty-four hours after a first, second and third degree burn sustained by falling on a stove. The extent of the burn is indicated in the diagram. Toxemia developed twenty-four hours after admission, as evidenced by high temperature, drowsiness and muscular twitchings. Exsanguinated 500 c.c.; transfused 680 c.c. There was an immediate and striking improvement in the child's condition, and a rapid fall in the temperature to normal. The rapidity of the recovery in this case was due in part to the relatively large amount of blood exsanguinated. In the early cases in which a much smaller exchange of blood was undertaken, the effect produced was less striking, and the operation had often to be repeated in order to effect a cure.

of erysipelas of the new-born (i. e., up to one month of age) is recorded as being close to 100 per cent., and in children from one to twelve months of age, as being 50 per cent. These published figures corre-

sponded very closely to our own until the adoption of exsanguination-transfusion. Since that time we have had six cases of erysipelas in the new-born, with three deaths, and fifteen cases in which the ages of the patients ranged from one to twelve months, with two deaths. All the fatal cases showed positive blood cultures for hemolytic streptococcus. This circumstance, however, does not necessarily mean that the method is of no value in such cases, as three of those that recovered had positive blood cultures also. Although this is only a small series, the reduction in mortality is sufficiently striking to merit attention. In the new-born, this reduction has been from nearly 100, to 50 per cent., and in cases where the patients' ages ranged from one to twelve months, from 50 per cent. to 13 per cent. (Table 1, and Figs. 7, 8 and 9).

TABLE 1.—*Erysipelas* *

	Medical Treatment		Exsanguination-transfusion	
	Died	Recovered	Died	Recovered
Under 1 month	5	1	3	3
1-12 months	13	14	2	13
Total	18	15	5†	16‡
	Mortality 56 per cent.		Mortality 23.8 per cent.	

* Summary of the treatment of erysipelas in children under one year of age by means of exsanguination-transfusion as compared with medical measures. By means of exsanguination-transfusion the mortality was reduced 50 per cent. in patients under one month of age and 37 per cent. in patients from one to twelve months of age .

† Blood cultures in all five positive for hemolytic streptococcus.

‡ Blood cultures in three cases positive for hemolytic streptococcus.

TABLE 2.—*Acute Intestinal Intoxication* *

Treatment	No. of Cases	Recovered	Died	Mortality
Exsanguination-transfusion	40	23	17	42%
Medical measures	36	12	24	66%

* Summary of the treatment of acute intestinal intoxication by exsanguination-transfusion and medical measures. By means of exsanguination-transfusion the mortality was reduced 24 per cent.

Acute Intestinal Intoxication.—Forty infants suffering from this condition were treated by exsanguination-transfusion, with seventeen deaths, a mortality of 42 per cent. (Table 2). These figures, when considered alone, are not very convincing, but when compared with a similar series of thirty-six cases treated medically with a mortality of 66 per cent., the improvement is striking. Much better results were obtained in the later cases than in the earlier ones in this series. This was due to a great increase in the amount of blood replaced in the later cases, and to the employment of the treatment in a higher proportion of cases before they appeared moribund. It is worthy of note that of eight cases which appeared to be moribund, four recovered following this operation, while of six similar cases treated medically, only one recovered.

The last case of acute intestinal intoxication treated by this method illustrates the results obtained. It was an infant twelve months old, admitted in a moribund condition on the fifth day of the disease. It was practically unconscious, appeared desperately toxic, and the circulation was obviously failing. Exsanguination of 760 c.c. was performed, with transfusion of 710 c.c. The amount introduced was less than the amount withdrawn on account of the failing circulation. Immediately after operation, there was slight improvement, which continued for the

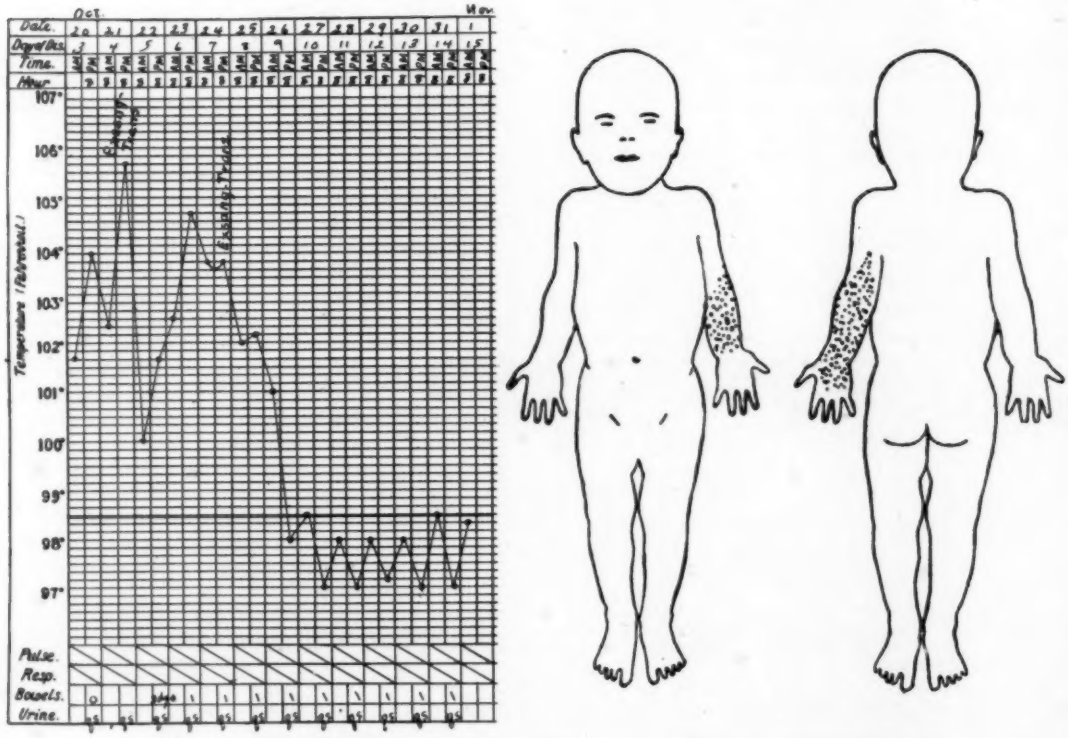

Fig. 7.—Temperature chart and drawing of a case of erysipelas. M.D., aged 11 months, two days before admission had a red spot appear on the wrist, which steadily increased in extent (see diagram). The child vomited and was feverish. Exsanguinated 200 c.c. blood, and transfused 270 c.c. twenty-four hours after admission. There was a rapid fall in temperature, but the rash continued to spread and the temperature subsequently rose. The operation was repeated four days after admission. The temperature fell immediately, and the rash disappeared. Rapid recovery followed. The blood-culture was sterile throughout. As experience with this method accumulated, it became evident that the result obtained was in proportion to the size of the exsanguination-transfusion. Consequently, in later cases the amount of blood exsanguinated and transfused was considerably increased (see Fig. 9). The foregoing patient was treated early in the series. The exsanguination-transfusion was relatively small and, in consequence, had to be repeated.

first twenty-four hours; by that time the child was decidedly better. The fourth day, the child was taking its feedings well, and in a week's time it was discharged as convalescent.

Poisoning by Drugs.—Since the introduction of exsanguination-transfusion, the opportunity has been offered on two occasions to try the method in cases of poisoning by drugs. These cases have been reported at length by Graham and Tisdall.[3] The patients were both young infants, suffering from severe eczema, who had been treated by the application of an ointment containing about 8 per cent. resorcin. About three days after the commencement of treatment, the babies suddenly collapsed. The skin became ashen and the pulse weak and

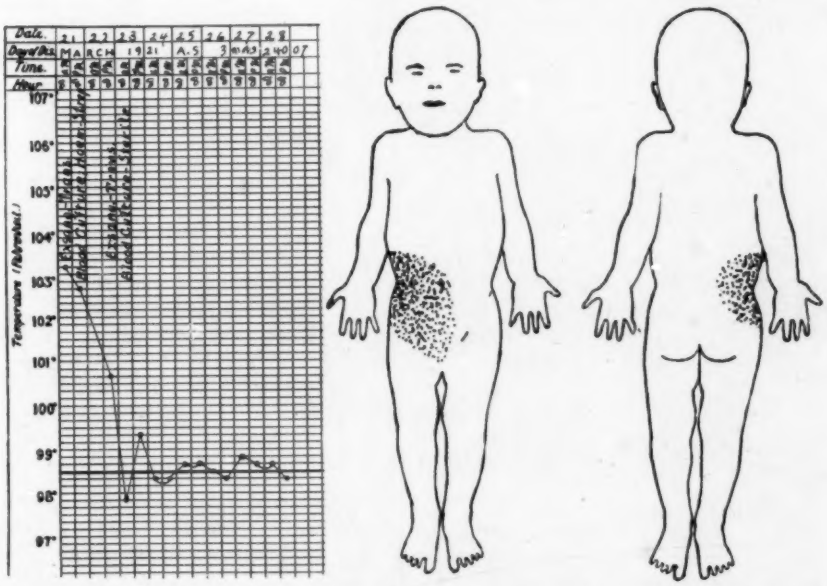

Fig. 8.—Temperature chart and drawing of a case of erysipelas with septicemia in an infant. A. S., aged 3 weeks, weighing 9 pounds (4.1 kg.), was circumcised two weeks before admission. One day before admission, the penis, scrotum and groin became swollen in the area indicated on diagram. The diagnosis was erysipelas. Exsanguinated 140 c.c.; transfused 240 c.c., on admission. Culture from the penis hemolytic streptococcus; blood-culture hemolytic streptococcus. There was a marked fall in temperature after exsanguination-transfusion, but the rash extended slightly. Exsanguination-transfusion was repeated on the day following admission. Two hundred cubic centimeters were withdrawn and 200 c.c. transfused. On this date, the blood-culture was sterile. There was a prompt fall in temperature and disappearance of the rash. The rapid improvement is the more remarkable in view of the age of the patient.

3. Graham, S. G., and Tisdall, F. F.: Canada. M. A. J. **12**:730-732 (Oct.) 1922.

thready. Within a few hours, convulsions and coma developed, and the patients gave every evidence of being moribund. Carboluria was present. At this stage, exsanguination-transfusion was performed and there was immediate improvement in the general condition; twenty-four hours later they had completely recovered.

A review of the literature shows that resorcin poisoning which has advanced to the stage of convulsions, coma and carboluria, such conditions as characterized our cases, is exceedingly fatal. The spectacular

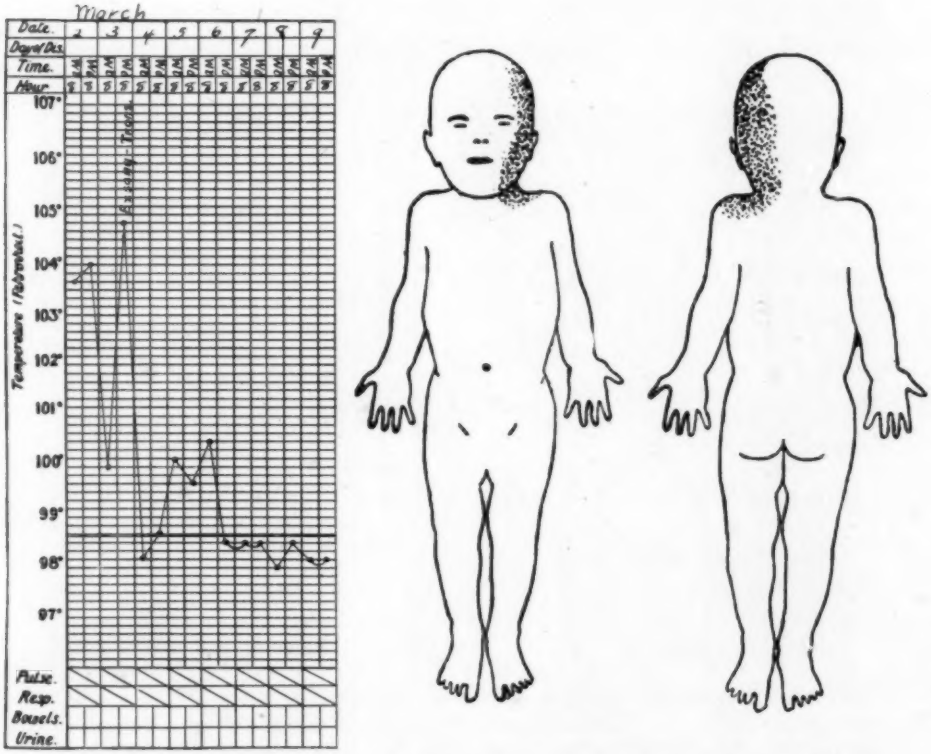

Fig. 9.—Temperature chart of a case of erysipelas in an infant. P. L., aged 8 months, weighing 17 pounds (7.7 kg.), was admitted with erysipelas of the face and scalp following incision of a suppurative cervical adenitis. See diagram for extent of lesion. Exsanguinated 670 c.c. and transfused 700 c.c. twenty-four hours after admission. The rash immediately ceased to spread and the temperature fell to normal. The rapid recovery in this case was due largely to the size of the exsanguination-transfusion.

recoveries left no doubt in our minds of the value of exsanguination-transfusion.

Malignant Scarlet Fever.—Five cases in this group were operated on, and all patients recovered. The symptoms were high fever (up to

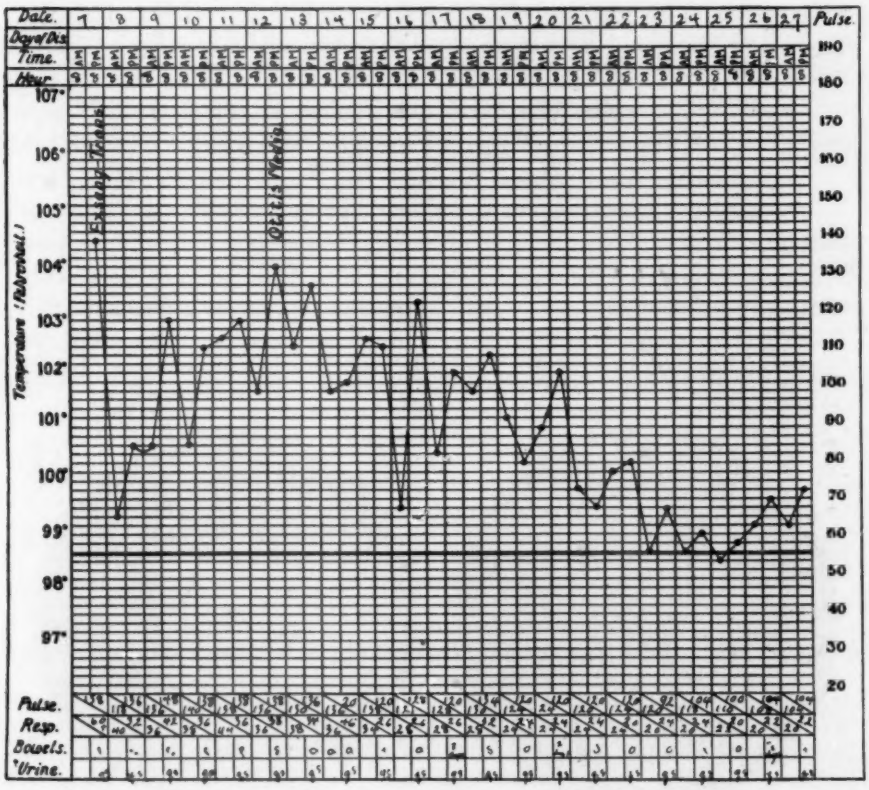

Fig. 10.—Temperature chart of a case of septic scarlet fever. Treated by exsanguination-transfusion. Recovery. A. F., aged 3 years, twenty-four hours before admission became suddenly ill with fever, delirium, vomiting and cyanosis. On admission, the patient was delirious, the temperature was 104 degrees, the palate was intensely congested with punctate hemorrhages scattered over it, the tonsils were much swollen, the tongue swollen and coated but with a definite red margin, the skin was mottled and cyanotic, and covered with small scattered pink papules, with slight erythemia about the axillae, and the cervical glands were swollen. Tentative diagnosis: acute septic scarlet fever (this was confirmed at a later date by the appearance of desquamation). Exsanguinated 500 c.c.; transfused 625 c.c., on admission. Rapid fall in temperature and improvement in general condition followed. The temperature subsequently rose and the patient ran through the ordinary course of scarlet fever complicated by otitis media. In this case, the operation apparently relieved the patient of the toxemia which overwhelmed him at the onset of the disease. The blood-culture was negative. Recovery followed.

105 degrees), faint rash, overwhelming toxemia, delirium and coma, and signs of circulatory failure. One of the patients had pericarditis. Exsanguination-transfusion was performed directly after admission. There was slight but immediate improvement, and by the next day the whole aspect of the condition had undergone a striking change for the better. The subsequent course was that of an ordinary severe scarlet fever (Fig. 10).

Septicemia.—The results in cases of septicemia apart from erysipelas so far have been less encouraging than the results in the case of toxemias. In the treatment of those diseases, in which there is an ineradicable source of supply of organisms, such as osteomyelitis, or in which the primary cause is a lung infection, the simple replacement of blood would seem likely to have only a temporary effect. If the "immune-transfusion" of Sir Almroth Wright should prove to be of

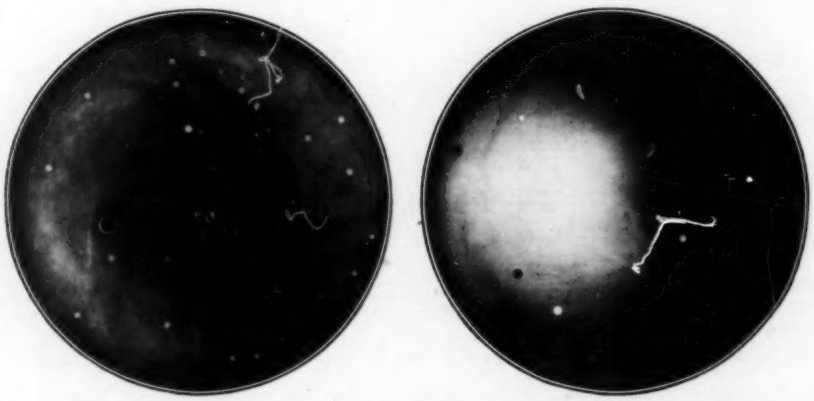

Fig. 11.—Photographs of quantitative blood-cultures on blood-agar plates to illustrate the striking reduction in the number of organisms in the blood immediately after exsanguination-transfusion for septicemia. Plate A (left) was made up of 1 c.c. of the patient's blood, obtained immediately before the operation, diluted with 9 c.c. of melted agar and immediately poured into a petri dish. Twenty-five colonies grew in forty-eight hours. Plate B (right) was made in a similar fashion from 1 c.c. of the patient's blood obtained at the end of the operation. Two colonies grew in twenty-four hours. The black spots are artifacts. The cultures were obtained from a patient with pneumococcic septicemia (not included amongst those mentioned in the text).

value, it is possible that the effect of his method might be greatly increased by combining it with exsanguination, which would at once get rid of the existing supply of toxin and bacteria in the blood. The accompanying photographs of plates of culture mediums (Fig. 11) illustrate the remarkable immediate effect of exsanguination-transfusion in diminishing the organisms in the blood. Exsanguination-transfusion has been performed for septicemia four times, with two recoveries.

These two patients showed blood cultures positive for hemolytic streptococci. The two fatal cases showed staphylococcus aureus in the blood cultures. All were extremely ill and appeared hopeless of recovery.

SUMMARY

1. The replacement of a considerable portion of an infant's or young child's blood is an operative procedure which can be carried out in any well equipped hospital.

2. In cases of severe superficial burns, in which the symptoms indicate a probable fatal result, exsanguination-transfusion has reduced the mortality from 100 to 50 per cent. Before the introduction of this procedure, we had not seen cases of burn toxemia recover after the development of convulsions.

3. In erysipelas of the new-born, the mortality has been reduced from nearly 100 per cent. to 50 per cent., and in cases where the patients were from one month to twelve months of age, it has been reduced from 50 to 13 per cent.

4. In acute septic scarlet fever, the method seems to be of decided value in tiding the patient over the period of intense toxemia as well as in converting the case into one of the ordinary severe type.

5. In acute intestinal intoxication, the adoption of exsanguination-transfusion has reduced the mortality by 20 to 25 per cent.; this includes all cases admitted in an apparently moribund condition.

6. The results in septicemia are, on the whole, somewhat disappointing. Although, in some, the response to treatment was most dramatic, in others, the benefit seemed to be slight and only temporary. Especially was this the case in staphylococcus infection and in endocarditis.

7. The subjects chosen for exsanguination-transfusion were suffering from conditions in which the mortality is extremely high. Any procedure, therefore, however radical, which may serve to reduce the mortality by 25 to 50 per cent., is worthy of serious consideration.

HEPATITIS, FOLLOWING CHOLECYSTOGASTROSTOMY *

EDWIN P. LEHMAN, M.D.

ST. LOUIS

The surgeon confronted with a permanently blocked common bile duct and an available gallbladder hesitates to employ the present operation of cholecystogastrostomy or cholecystenterostomy on account of the probability of the ultimate development of liver infection. This result not only is shown in clinical experience, but can be demonstrated experimentally. Gatewood and Poppens,[1] after extensive experimental production of cholecystogastrostomies, cholecystenterostomies and cholecystocolostomies in the dog, came to the following, among other, conclusions: "All livers become infected sooner or later if the method employed in our experiments be followed. Cholecystenterostomy, from an experimental standpoint, is not an operation to be recommended for use except in well-selected cases such as carcinoma of the pancreas, where the temporary comfort of the patient is paramount; or irreparable common duct obstruction." This paper furnishes an excellent general review of the subject from the clinical and experimental aspects.

The present study is an attempt to devise a method of sidetracking the bile with the single end in view of avoiding ultimate liver infection. Undoubtedly, all gallbladders connected directly with the intestinal or gastric lumen will, in the dog, become infected. The problem, then, is to prevent this infection from spreading to the liver.

The routes of infection to and from the liver have been worked out by Graham and his associates,[2] who emphasize particularly the direct lymphatic connection between the liver and the gallbladder, as described by Sudler. Graham believes that one of the important results of removing a functionating gallbladder, the wall of which shows even minute inflammatory lesions, is the breaking of a vicious circle of infection. The wall of such a gallbladder will harbor organisms, which will pass via the lymphatics to the liver. The inflammation in the liver will then

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* From the Department of Surgery, Washington University School of Medicine.

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continue to feed organisms via the same route or via the periductal lymphatics to the wall of the gallbladder. The richness of the lymphatic communication between gallbladder and liver makes the rôle played by the lymphatics accompanying the biliary ducts difficult to estimate. Whether or not there can be an ascending infection along the hepatic ducts to the liver, and if there be such a process what its relative importance is as compared with the direct gallbladder to liver path,

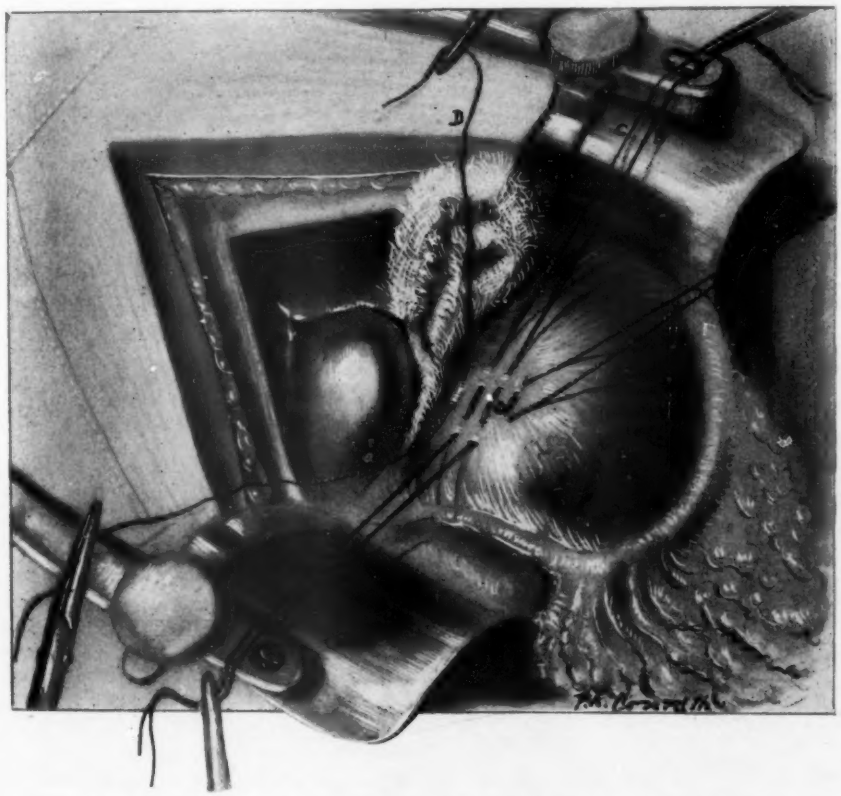

Fig. 1.—Method of anastomosing the cystic duct to the stomach.

become important questions. It was hoped that the method of attack on the primary problem, namely, an attempt to break mechanically the cholecystohepatic lymphatic connection, might throw light as well on these questions.

The experiments, carried out on dogs, consisted, with one exception, of cholecystogastrostomies combined with double ligation and division of the common duct. In the one exception noted, the anastomosis was made with the duodenum. Four groups of dogs, totaling 47, were operated on, as follows:

1. The controls consisted of nine dogs, on which cholecystogastrostomy was performed, with double ligation and division of the common duct.

2. On twelve dogs, cholecystogastrostomy, with double ligation and division of the common duct, was performed. Prior to the anastomosis, the gallbladder was dissected from its liver attachment.

3. The same operation as that described above was performed on eight dogs. In addition, a flap of the falciform ligament containing fat was wrapped about the gallbladder. In all but two dogs, this was a free transplant.

4. On eighteen dogs, double ligation and division of the common duct was accomplished. The cystic duct was then anastomosed to the stomach by the following method:

The gallbladder was emptied by gentle pressure, and the common duct doubly ligated and divided between the ligatures. The gallbladder was then separated from the liver by sharp and blunt dissection down to the cystic duct, and the fossa packed. Seromuscular sutures were introduced into the stomach as shown in Figure 1. Suture D was passed through the subserosa of the inferior surface of the cystic duct at a point (not shown in the drawing) so chosen as to avoid tension on the duct when it was approximated to the stomach. The stomach was then drawn out of the wound and, after packing off completely, an opening between two stay sutures was made on the posterior surface in the cardiac half. This was just large enough to admit an Ochsner hemostat which was thrust through the lumen and brought out through an opening on the anterior surface made at the small circular marker between sutures A and B. It was then passed beneath the loops of sutures B and C and clamped to the abdominal wall, while the gallbladder was opened and emptied. The hemostat next seized the gallbladder, and drew it under the loops of sutures B and C and completely through the stomach, until the cystic duct fitted snugly the opening in the anterior wall. Sutures D, C, B, and A were tied in the order named. Suture D thus prevented retraction of the cystic duct, and sutures C, B, and A buried it in a furrow of stomach wall, just as in a Witzel gastrostomy. The gallbladder was next amputated by the actual cautery as near the posterior surface of the stomach as possible, and the stump allowed to retract into the stomach. Closure of the posterior opening in the stomach by purse string sutures and a reenforcing row of Lembert's sutures anteriorly completed the operation.

The last three groups of experiments were made in the order named. It became obvious after a few survivals of group 2 that the gallbladder became adherent in its old fossa, and that a reestablishment of lymphatic connections could not be ruled out. Similarly, in group 3,

the interposition of a fatty flap of falciform ligament would not prevent the formation of such adhesions. All that remained of the transplant, after several weeks, consisted of a few small globules of fat in the midst of adhesions (Fig. 2), and again one could not with certainty, rule out the reestablishment of lymphatic channels. Finally, then, the attempt represented by group 4, was made to do away with the gallbladder completely, and thus to eliminate all possibilities of reestablishment.

The technical difficulties of operation in this field in the dog have been noted by previous experimenters. The gallbladder of the dog is vascular and delicate. The slightest handling with instruments, even

Fig. 2 (Dog 16.)—The gallbladder was freed from the liver before being anastomosed to the stomach, and a fatty segment of falciform ligament wrapped about it. In the drawing, made one hundred thirty-five days after operation, the gallbladder was dissected from the liver, where it had become adherent, to show the small amount of fat representing the remains of the falciform flap; note the dilation of the common duct.

with a rubber-covered clamp to control the flow of bile while the organ is open, results in free bleeding either into the lumen or into the gallbladder wall itself. Inability to clamp off the flow of bile always results in a certain amount of peritoneal soiling, no matter how carefully the organ be packed off. Such soiling includes at least a small

amount of infective material from the stomach mucosa. Hemorrhage and peritonitis are thus frequent causes of early death.

It is convenient to classify the deaths of experimental animals into (1) early and (2) late. The former class includes only the deaths from operative handling, hemorrhage and peritonitis. The latter class includes the deaths from biliary obstruction, liver infection and intercurrent disease.

Gatewood and Poppens [1] performed twenty cholecystogastrostomies with an immediate operative death in two, and death from peritonitis in four, or total early mortality of 30 per cent. This operation is identical with the control operation of this study. With the preliminary operative experience of nine dogs in group 2, I was able, fortunately, to avoid all early mortality in my control group.

In the other groups, however, the early mortality was high. In group 2 it was 66⅔ per cent.; in group 3 it was 50 per cent.; in group 4, 83⅓ per cent. The percentage in group 3 is improved over that in group 2, undoubtedly because of small refinements of technic taught by the early fatalities. However, no amount of care in handling the gallbladder or in protecting the general peritoneum would prevent a high incidence of peritonitis. Only in one or two instances was this due to a leaking suture line. The difference in mortality rate between the controls and the various experimental groups must be ascribed to the greater trauma to the peritoneum, the gallbladder, and perhaps the liver itself. The amount of soiling in the controls and the experiments was, on the average, about equal.

This high early mortality is of importance in this study from two angles: (1) It cuts down enormously the dogs available for pathologic study. (2) It makes the applicability to the human being of these operations, even if theoretically sound, doubtful indeed. However, such application need not be completely dismissed on the basis of experimental results. The gallbladder in man can be handled with less risk of injury. Furthermore, the gastric contents are much less infective, and their escape, as well as the escape of bile into the peritoneum, can be almost completely controlled.

As Gatewood and Poppens have remarked, unless the common bile duct is divided between two ligatures, the lumen will be reestablished and the cholecystogastric fistula will close spontaneously. Closure of the fistula occurred in two dogs of the present series, where an anomalous duct was mistaken for the common duct. If the duct is divided properly, and if the original size of the fistula is relatively large, it remains amply patent. If it is small, occasionally the contraction of the surrounding scar tissue may narrow its diameter so that partial biliary stasis occurs. In no such case, was there complete stenosis of the fistula. One animal of group 4 shows that the operation there

employed is feasible if technical difficulties are overcome. In this dog, the cystic duct had healed into the stomach and was discharging bile freely. The accidental resemblance of the artificial opening to the normal papilla of Vater was striking (Fig. 3).

In all dogs in which there was free discharge of bile through the artificial opening, the pathology of gallbladder and ducts was uniform. The gallbladder was filled with bile, often inspissated, practically always containing hair and stomach contents. Its wall was white and thickened.

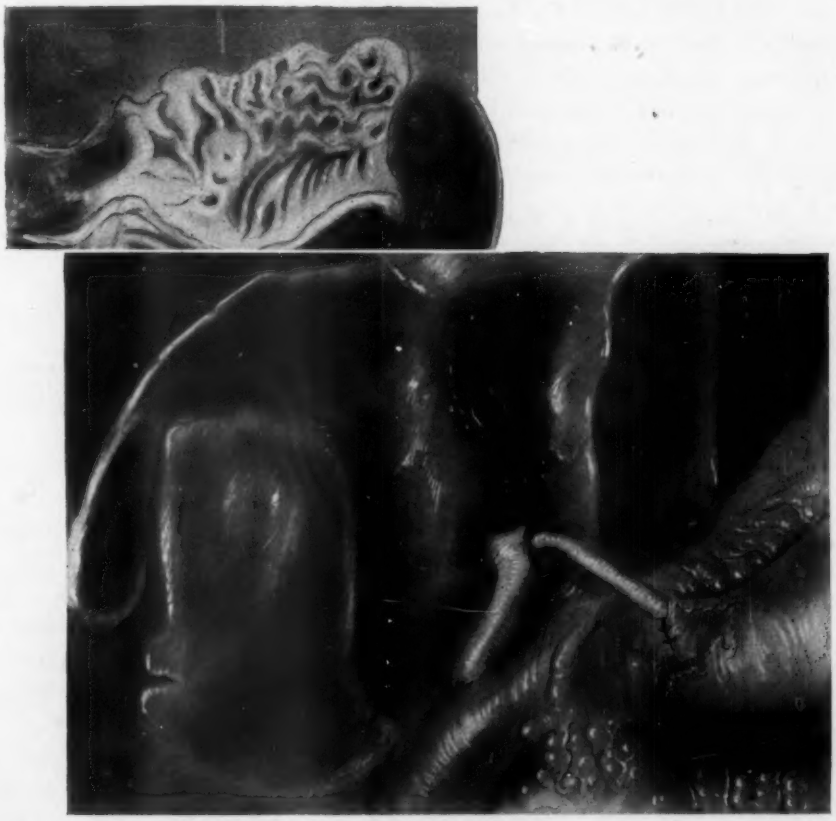

Fig. 3 (Dog 20).—Adhesions between the stomach and liver have been dissected free; the cystic duct is seen disappearing within a fold of the stomach wall; note the dilation of the common duct. The insert shows the artificial papilla through which the cystic duct opens into the lumen of the stomach.

The common and adjacent hepatic ducts were dilated to the point of ligature (Figs. 2 and 3). The livers showed various changes in the gross, but none appeared normal. The peritoneum showed various degrees of adhesion. The tendency for the gallbladder to become adherent in its fossa, whether or not a flap of falciform ligament be interposed, has already been described.

The results of microscopic study of the livers are recorded in the tables. It is obvious that the livers of dogs dying in the first few days of hemorrhage or peritonitis are of no significance for the purpose of this study. They are therefore not included in the tables. In the second column, "Days," is given the length of the survival of each dog. A "perfect" operative result is recorded when the interruption of the common duct was shown to be complete, and the bile was discharging into the stomach through a generous stoma.

In reviewing these tables, several comments suggest themselves. The slight infection of the liver in dog 1 present in spite of an open common duct and a closed stoma. The cause for this infection may be seen in a chronic cholecystitis, which presumably had its origin at the time the stoma was still patent. In the long time dogs in group 1 (6, 7, 8, 9), the liver picture is fairly uniform. The presence of hepatitis is unquestionable.

Results of Experiments

Group 1—Control

No.	Days	Death	Operation	Microscopic Study of Liver	Remarks
1	50	Killed	Faulty	Slight central necrosis; scattered polymorphonuclears	Common duct functionating and stoma healed; gallbladder wall infected
2	7	Killed	Perfect	Marked central necrosis; few polymorphonuclears	Killed on account of panophthalmitis
3	10	Liver necrosis	Perfect	Massive central necrosis; moderate leukocytic infiltration	
4	16	Pneumonia	Perfect	Chronic passive congestion; slight infiltration with polymorphonuclears largely periportal	
5	6	?	Perfect	Very marked fatty degeneration; slight polymorphonuclear infiltration	
6	127	Killed	Perfect	Moderate periportal inflammation; slight fatty degeneration	
7	123	?	Perfect	Periportal inflammation, acute and chronic	Gradual failure with marked emaciation
8	214	Killed	Perfect	Marked fatty degeneration; diffuse and miliary leukocytic infiltration	
9	184	Killed	Perfect	Marked leukocytic infiltration, diffuse and miliary; portal fibrosis	

Group 2*

No.	Days	Death	Operation	Microscopic Study of Liver	Remarks
10	160	Killed	Perfect	Slight fatty degeneration and fibrosis; marked miliary and diffuse leukocytic infiltration	Anastomosis with duodenum
11	56	?	Faulty	Very marked acute and chronic inflammation; fatty degeneration; jaundice	Stoma contracted to minute opening
12	84	Killed	Perfect	Marked diffuse and miliary leukocytic infiltration; small areas of necrosis; moderate fatty degeneration	Dog had unexplained spastic quadriplegia before being killed. (Epidemic in dog room.)
13	51	Killed	Perfect	Very marked acute and chronic inflammation, diffuse and miliary, and marked fatty degeneration	Dog had same condition as Dog 12

Group 3 †

No.	Days	Death	Operation	Microscopic Study of Liver	Remarks
14	38	?	Perfect	Marked acute and chronic inflammation; jaundice; central necrosis	Died in condition recorded in Dogs 12 and 13
15	86	Pneumonia	Perfect	Chronic passive congestion; moderate acute and chronic inflammation	
16	135	Killed	Perfect	High grade fibrosis with polymorphonuclear infiltration; very marked fatty degeneration	See Fig. 2
17	81	Killed	Perfect	Moderate diffuse and miliary leukocytic infiltration; marked fatty degeneration	Killed in same condition as Dogs 12, 13 and 14

Group 4 ‡

No.	Days	Death	Operation	Microscopic Study of Liver	Remarks
18	84	Killed	Faulty	Marked periportal inflammation with definite abscess formation; slight bile stasis	Jaundiced from mechanical constriction of cystic duct by suture D
19	190	Killed	Faulty	None made	Anomalous common duct tied; common duct functioning; stoma healed
20	79	?	Perfect	Marked fatty degeneration; marked periportal chronic inflammation with moderate polymorphonuclear infiltration	No cause for death found

* In addition, there were 8 dogs in this group dying of hemorrhage, and peritonitis.
† In addition, there were 4 oogs in this group dying of hemorrhage and peritonitis.
‡ In addition, there were 15 dogs in this group dying of hemorrhage and peritonitis.

In group 2, the gross findings of adhesion of the gallbladder in its old fossa is of the greatest importance. All the dogs show inflammatory changes in the liver.

In group 3, the cause for the jaundice shown in the liver of dog 14 is not clear. No general jaundice was observed in the gross, and no gross biliary obstruction occurred. In general, the dogs here show as marked inflammatory changes in the liver as do the dogs of group 2. In the gross, the gallbladders were adherent to the liver in every case.

In group 4, the high early mortality gives us but two dogs to study. These, however, show definitely (1) that the operation of implantation of the cystic duct into the stomach is possible; (2) that this operation does not prevent hepatitis.

In conclusion, one fact is obvious, namely, that communication between the stomach and the lumen of the gallbladder or cystic duct is associated with infection of the liver. No variation of the mechanical plan of the operation has prevented hepatitis. It is certain, in dogs 18 and 20, that the cholecystohepatic lymphatics were destroyed, and that the only channels open to the liver from the lumen of the cystic duct were the bile itself, and the periductal lymph channels. Yet the liver, in these dogs, presented the same picture of infection as those livers in which the more direct route was available.

CONCLUSIONS

1. Infection of the liver from an infected gallbladder can occur via the periductal lymphatics.

2. No one of three attempted variations of the mechanical plan of cholecystogastrostomy will prevent this occurrence.

3. A new operation for implanting the cystic duct into the stomach is surgically possible, although attended experimentally by a high mortality. It may prove of value in experimental studies.

LIGATION OF THE PULMONARY ARTERY OF ONE LUNG WITH AND WITHOUT RESECTION OF THE PHRENIC NERVE*

EXPERIMENTAL STUDY

KARL SCHLAEPFER, M.D.

NEW HAVEN, CONN.

I. Introduction. Surgical procedures additional to climatic-hygienic regimen in chronic inflammatory conditions of one lung (tuberculosis).

II. Clinical data.

A. Eradicating procedures (pneumectomy).

B. Supplementary procedures, putting the lung to a rest by indirect action.

1. Artificial pneumothorax.
2. Pneumolysis and plombierung.
3. Extrapleural thoracoplasty; paravertebral method (Sauerbruch); scapulo-paravertebral method (Brauer).

C. Anatomy and physiology of the lungs following these procedures.

D. Supplementary procedures, acting directly on the lung.

1. Ligation of the pulmonary artery. Report of cases.
2. Plugging of the main bronchus.
3. Partial occlusion of the pulmonary veins.
4. Ligation of the bronchial artery.
5. Auxiliary procedures to 1-3.
   (*a*) Extrapleural thoracoplasty.
   (*b*) Plombierung.
   (*c*) Phrenicotomy.
   (*d*) Resection of intercostal nerves.

III. Experimental data.

A. Rabbit series.

1. Anatomic data.
2. Technic of operation.
3. Postoperative course.
4. Protocols—summary of findings.

B. Dog series.

Anatomic data.
Technic of operation.
Postoperative course.
Protocols
   (*a*) Ligation of the pulmonary artery; summary of findings.
   (*b*) Ligation combined with resection (crushing) of the phrenic nerve; summary of findings.

C. Discussion of the experimental findings (anatomic changes, physiology).

IV. Conclusions.

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* From the Surgical Hunterian Laboratory of the Johns Hopkins University, Baltimore.

INTRODUCTION

Chronic inflammatory conditions of the lung result from a continuous intensive struggle of the organism against an invasive infective agent, whereby the general resistance of the body is lowered so much that it is unable to withstand the infection. In more or less circumscribed regions the imported micro-organisms remain alive. The body keeps them in check by enveloping them in a covering of fibrous tissue, thus isolating the diseased areas from the other parts of the organism. So the infective agents are put under gradually less favorable living conditions. The reactionary envelop forms a wall against the exotoxins and endotoxins of the encapsulated bacteriae. It also diminishes their metabolic exchange with the host. But these chronic foci of infection in lungs form a source of constant menace for the bearer, the barrier being only a relative one. The general resistance of the host is constantly endangered. If it is lowered beyond a certain level by an intercurrent disease, the infection can become active after being silent for a long period of time. A first relapse may be overcome. A subsequent one may prove fatal by generalization of the hitherto localized lesion.

This is particularly true in the most frequent condition occurring in this group, chronic tuberculosis. This fact forms the basis of all these experiments. Bronchiectasis, actinomycosis, spirochetosis and woolsorters' anthrax, when restricted to a circumscribed area in one lung, may have a similar clinical appearance and pathologic picture. Even primary new growths in an early stage can present a circumscribed lesion with an inflammatory zone of reaction which may be increased by a chronic congestion with subsequent fibrosis, as will be demonstrated following ligation of the pulmonary artery. As the basis for our study, we have in mind only those cases which are suitable for the proposed therapeutic procedures in which the lesion is more or less localized to one side, so that the other side can take over the whole respiratory function without interference with small foci perhaps present. These may heal under the resulting hyperemia of this organ. The second essential factor is the clinical evidences of resistance of the organism as demonstrated pathologically by the tendency to encapsulate the lesion by a fibrous envelop. Our surgical aim is to develop and increase this physiologic repair process.

These two conditions are also generally recognized prerogatives for the surgical proceedings hitherto used in chronic unilateral inflammatory conditions, especially tuberculosis. For the cure of lesions of this kind, surgical procedures were devised to eradicate the chronic focus of infection. Exstirpation of the diseased lung or lobe was successful only in a few instances. The removal of the diseased organ in these

patients with a long-standing illness is generally too great an operative risk when performed in one stage, the general resistance being lowered too much by the chronic disease in the lung.

So it is quite conceivable why different attempts were made to diminish the severity of the operative procedure by putting the diseased lung at physiologic rest, hitherto mostly by measures acting indirectly, the organism being thus enabled to combat the local ill-effect of the infection (or the new growth) by almost completely suppressing its action on the body. The chronic congestion resulting in one lung put to a functional rest causes, as is generally known, a fibrous-tissue growth, which is added to the reactionary fibrous envelop around the infected area. This fibrosis in the lung is a process analogous to that observed in any parenchymatous organ (kidney, liver, pancreas) in the latest stages of chronic congestion. These two sources may prove to be sufficient to bring the lesion to a permanent clinical cure; or the diseased organ becomes in this way at least well prepared for a secondary eradicating operation, such as lobectomy or pneumectomy. The latter, as a second stage procedure, is a lesser shock to the patient than when done in one stage, owing to the fact that the one sound lung had ample time to take over the whole respiratory function.

The experiments to be described in this paper were performed in the endeavor to get a good understanding of the pathologic and physiologic changes following a new method, putting the one lung to a physiologic rest by direct action through ligation of the pulmonary artery without and with resection of the phrenic, instead of using indirectly acting methods hitherto generally accepted, such as artificial pneumothorax, and extrapleural thoracoplasty. Advanced unilateral chronic inflammatory lung conditions which do not yield to dietetic and climatic treatment alone, especially cases of tuberculosis, the most common form of this group, may be benefited by our study.

A short review of the methods hitherto used and their results will be followed by a few clinical observations obtained with the new method. Our experimental findings on rabbits and dogs will be discussed, together with the findings of previous co-workers along the same line. These experiments will elicit the factors governing the physiologic reparatory processes occurring in man after these procedures. They will give us a clue as to the duration which each process demands. The clinical observations treated in the different ways will be compared, allowing us to draw some conclusions as to the prospects offered by the present and the new procedures in the fight against chronic advanced unilateral inflammatory conditions of one lung, particularly against the greatest scourge of man, chronic tuberculosis. A glimpse might be obtained as to the practicability of these procedures for similar conditions restricted to one lung, such as bronchiectasis and lung abscess, and in early cases of primary new growths.

I. CLINICAL DATA

A. Pneumectomy: Extirpation of the Diseased Lung (Total or Partial).—The only eradicating procedure, used hitherto in few instances, is the extirpation (pneumectomy) of diseased lobes. Successful operations are reported by Krönlein, Helferich, Körte, Garré,[1] Heidenhain,[2] W. Meyer,[3] Robinson,[4] Graham [5] and Lilienthal.[6] Various complications following these operations give a high mortality. The infection in the lung is generally so widespread that the field of operation cannot be kept under aseptic conditions. In the presence of the very susceptible pleura, the reaction to any kind of infection is much more perilous than in the peritoneal cavity. Any inflammatory reaction within adhesions to the chest wall in the neighborhood of a tuberculous focus endangers the operative result, threatening the patient either with a mediastinitis, as a sequel of a retracting bronchial stump, or a secondary empyema resulting from an infection at the time of operation. Because of the lowered resistance of these chronically sick patients, the risk in pneumectomy is great. Even in uncomplicated cases, the closure of the stump of the bronchus was one constant source of anxiety, owing to the fact that the bronchi in these cases are always infected. One-stage pneumectomy is generally too great a risk for the patient to be recommended. Graham [5] compiled forty-eight cases of lobectomy for bronchiectasis, with a mortality of 52 per cent. It is probable, Graham concludes, that improvements in methods will greatly reduce the mortality, although infection of the wound seems unavoidable. Whether lobectomy is more practicable when preceded by a preliminary ligation of the pulmonary artery combined with resection of the phrenic nerve is a point which will be discussed later.

B. Indirectly Acting Methods for Putting the Lung to a Physiologic Rest.—1. Artificial pneumothorax. In cases of unilateral tuberculosis, the artificial pneumothorax treatment, as introduced by For-

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5. Graham, E. A.: Surgical Treatment of Bronchiectasis, Arch. Surg. **6**: 321 (Jan.) 1923 (Pt. 2).

6. Lilienthal, H.: Resection of the Lung for Suppurative Infections, Ann. Surg. **75**:257 (March) 1922.

lanini,[7] Murphy,[8] Brauer[9] and Spengler,[10] is the procedure of choice, when there are no dense adhesions between the parietal and the pulmonary pleura. If adhesions are present, a partial pneumothorax is obtained, which sometimes can be transformed into a total one by increasing the pressure in the pneumothorax cavity, breaking up the adhesions between the two pleural sheaths. Only a total pneumothorax is effective in this therapy, guaranteeing a complete collapse of the diseased lung, whereby it is put to a complete physiologic rest, stopping any air exchange in this organ. Jacobaeus [11] advised the use of an endoscope (thoracoscope), which is introduced through a thoracotomy wound into the pleural cavity, in the endeavor to burn off the adhesions along the chest wall. Jacobaeus' suggestion was found practicable by only a few therapists, as in the majority of these cases higher pressure within the pneumothorax cavity leads gradually, and thus in a safer way, to the same result. The danger of air embolism must always be kept in mind in breaking up these adhesions, either by the usual way through lung veins and the left side of the heart (erroneously called pleural reflexes [Schlaepfer][12]), or through abnormal collaterals of superficial lung veins to the upper thoracic veins into the right side of the heart. This second manner was studied by Guyot.[13] Experimentally, I confirmed

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7. Forlanini, C.: Una contribuzione della terapia chirurgica della tisi. Ablazione del pulmone pneumotorace artificiale? Gaz. d. osp., August-November, 1882; Die Behandlung der Lungenschwindsucht mittelst künstlichem Pneumothorax, Ergebn. d. inn. Med. u. Kinderh. **9**:621, 1912.

8. Murphy, J. B.: Surgery of the lung, J. A. M. A. **31**:151 (July) 1898.

9. Brauer, L.: Die Behandlung der einseitigen Lungenphthisis mittelst. künstlichem Pneumothorax, München. med. Wchnschr., 1906, No. 7, p. 338; Die therapeutische Bedeutung des künstlichen Pneumothorax, Klin.-therap. Wchnschr., 1908, No. 20. Brauer, L., and Spengler, L.: Erfahrungen und Ueberlegungen zur Lungenkollapstherapie. 2. Die Technik des künstlichen Pneumothorax, Beitr. z. Klin. d. Tuberk. **14**:418-476, 1909.

10. Spengler, L.: Zur Chirurgie des Pneumothorax, Beitr. z. klin. Chir. Tuberk. **49**:68, 1907; Dauererfolge bei. Behandlung schwerer einseitiger Lungentuberkulose mittels künstlichem Pneumothorax, München. med. Wchnschr. **58**:460, 1911.

11. Jacobaeus, H. C.: Endopleurale Operationen unter Leitung des Thoracoscops., Beitr. z. Klin. d. Tuberk. **35**:35, No. 1, 1915; Cauterization of Adhesions in Pneumothorax Treatment of Tuberculosis, Surg., Gynec. & Obst. **32**:493 (June) 1921.

12. Schlaepfer, Karl: Die intrapleuralen Reflexe und ihre Bedeutung bei operativen Eingriffen, Ergebn. d. Chir. & Orthop. **14**:797-905, 1921; Air Embolism Following Various Diagnostic or Therapeutic Procedures in Diseases of the Pleura and the Lung, Bull. Johns Hopkins Hosp. **33**:321 (Sept.) 1921.

13. Guyot, G.: Sulla vascolarizzatione delle cotenne pleuriche e rapporto di essa col. circulo dell arteria pulmonare, Clin. med. ital. **45**:640-654, 1906.

Guyot's statement, and was able to show its clinical importance, in a recent publication of mine.[14]

2. Pneumolysis. In exceptional cases, when the tuberculous process is restricted to one lobe, generally the upper one, Tuffier [15] and Baer [16] advised the extrapleural plombierung (pneumolysis); i. e., mobilization of the parietal pleura over the diseased area from the rigid chest wall and interposition of fat or a paraffin mixture of special melting point as a compressing agent of the lung. The action of this plombierung is analogous to that of the gas in the pneumothorax cavity, forcing the adjacent lung to collapse. Being extrapleural, this therapy is effective in cases in which widespread adhesions render the use of the artificial pneumothorax impossible. The diseased area on this one side must be well circumscribed to one lobe, preferably the upper one.

3. Extrapleural thoracoplasty. In cases in which the tuberculous process is disseminated throughout one lung, as in the majority of instances in which the pleural cavity is obliterated to a great extent, the extrapleural thoracoplasty, as worked out by C. Spengler,[17] Brauer,[18] Friedrich,[19] Wilms, [20] Sauerbruch [21] and Bull [22] is the treatment of choice. We mobilize the rigid bony chest wall by multiple rib resec-

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14. Schlaepfer, Karl: Collateral Circulation Following Chronic Obstruction of the Pulmonary Veins and Its Relation to Air Embolism Following Various Diagnostic and Therapeutic Procedures (Pneumolysis), Surg., Gynec. & Obst. **37**:510, 1923; Beitr. z. Klin. d. Tuberk. Würzb. **57**:98, 1923.

15. Tuffier: Etat actuel de la chirurgie intrathoracique, Paris, 1914.

16. Baer: Beiträge zur Klinik des künstlichen Pneumothorax, Ztschr. f. Tuberk. **29**:129, 1918.

17. Spengler, Carl: Ueber Thoracoplastik und Höhlendesinfektion bei Lungenphthise, Deutsch. med. Wchnschr. **29**:312, No. 18, 1903.

18. Brauer, L., and Friedrich: Ueber Lungenchirurgie, Verh. d. Ges. deutsch. Naturforscher u. Aerzte, Leipzig **1**:166, No. 2; 1909; Erfahrungen und Ueberlegungen zur Lungenkollapstherapie. Die ausgedehnte extrapleurale Thoracoplastik, Beitr. z. Klin. d. Tuberk. **12**:49-154, 1909; Ueber eine neue Methode zur Verengerung des Thorax bei Lungentuberkulose, München. med. Wchnschr., 1911, No. 15, p. 1203; Das Ziel und die Abarten der extrapleuralen Thoracoplastik, sowie die Methodik der subskapular-paravertebralen Form, Beitr. z. Klin. d. Tuberk. **51**:319, 1922.

19. Friedrich, P. L.: Die operative Beeinflussung einseitiger Lungenphthise durch totale Brustwandmobilisierung und Lungenentspannung, Arch. f. klin. Chir. **87**:588-624, 1908; Ueber Lungenchirurgie insbesondere über die neueren chirurgischen Heilbestrebungen bei Emphysem und Tuberkulose, München. med. Wchnschr. Nos. 47 and 48, pp. 2417-2494, 1908; Der Raumausgleich in der Brusthöhle nach einseitiger Lungenamputation, Arch. f. klin. Chir. **87**:647, 1908; Weitere Fragestellungen und Winke für die operative Brustwand-Mobilisierung, Deutsch. Ztschr. f. Chir. **100**:181, 1909; Die Chirurgie der Lungen, Arch. f. klin. Chir., **82**:1147, 1907; Thoracic Surgery, J. A. M. A. **53**:1970 (Dec. 11) 1909.

(Footnotes 20, 21 and 22 on next page)

tion, thus diminishing its circumference, acting indirectly on the lung by forcing it to a partial collapse and reducing its functional activity. The paravertebral resection of Sauerbruch is one well-known method whereby pieces of rib from 3 to 4 or 5 to 6 cm. in length are resected from the first to the eleventh rib posteriorly in the paravertebral line. The bony chest wall is so mobilized that the lung can partially collapse. It can be compared in this effect to a partial artificial pneumothorax. A total collapse of the lung is the form which guarantees an almost complete suppression of the respiratory air exchange. This is obtained by Brauer's subscapular paravertebral rib resection, a method which takes parts of the first to the tenth ribs for a length of from 1 to 16 cm. A special effort is made to mobilize the whole chest area under the scapula.

Following thoracoplasty, the tuberculous lesion heals gradually by fibrous tissue formation, which envelops the diseased area in a dense impermeable covering. The tuberculous areas become encapsulated, and the infection is checked. This fibrosis is superimposed on the connective tissue formation resulting from reaction around the areas of infection. After a considerable lapse of time (from one to two years), the infection subsides, leaving a dense scar of fibrous tissue, sometimes with calcification.

C. Anatomy and Physiology of the Collapsed Lung.—A review of the anatomic-pathologic changes and physiologic processes in the lung forced to a rest by methods acting indirectly, such as artificial pneumothorax, pneumolysis and extrapleural thoracoplasty, will give us an understanding of analogous procedures presented later for the same therapeutic purpose. Although gradual variations of the degree of collapse of the lung are encountered in the different methods, the phenomena (principles) governing these processes are the same (Sackur [23])

20. Wilms, M.: Eine neue Methode zur Verengerung des Thorax bei Lungentuberkulose, München. med. Wchnschr. No. 15, 1911, p. 77; Welche Formen der thoracoplastischen Pfeilerresektion sind je nach Ausdehnung und Schwere der Erkrankung zu empfehlen? München. med. Wchnschr. No. 9, 1913, 449; Die Fortschritte in der operativen Behandlung der Tuberkulose, Deutsch. Ztschr. f. Chir. **129**:654, 1914.

21. Sauerbruch, F., and Elving: Die extrapleurale Thoracoplastik, Ergebn. d. inn. Med. Kinderh. **10**, 1912; Die chirurgische Behandlung der Lungentuberkulose mit extrapleuraler Plombierung, Bruns Beitr. z. klin. Chir. **90**: 247, 1914; Die Chirurgie der Brustorgane, Berlin, 1920, p. 573.

22. Bull, P.: Thoracoplasty in Treatment of Pulmonary Tuberculosis, Norsk. Mag. f. Laegevidensk. **80**:1105 (Nov.) 1919; Extrapleural Thoracoplasty in the Treatment of Pulmonary Tuberculosis, Brit. Med. J. **2**:1217 (Dec. 23) 1922.

23. Sackur: Zur Lehre vom Pneumothorax, Ztschr. f. klin. Med. **29**, 1896. Weiteres zur Lehre vom Pneumothorax, Virchows Arch. f. path. Anat. **150**: 151, 1897.

Collapse of the lung guarantees a certain immobilization of the foci of infection within the surrounding inflammatory zone of reaction. The push and pull at every respiratory movement is done away with, and thus intermittent irritation of the tissue is obviated. The respiratory immobilization and the lung collapse lower the rate of the blood current. Stasis is present, more pronounced, when the diaphragm is immobilized by resection of the phrenic nerve. This stasis especially involves the larger blood vessels (arteries and veins), but affects the capillaries also.

With a plethysmograph, Cloetta [24] and Anderes [25] were able to show that the collapsed lung has a relatively larger blood content than the normally distended lung. Sauerbruch [21] thought that there was a greater blood flow through the collapsed lung. Only the quantity of blood resulting from stasis is, relatively, great. The circulation through the obstructed lung is undoubtedly greatly diminished, as demonstrated by Le Blanc,[26] showing that the blood in the systemic circulation has about the same oxygen saturation as in a normal organism using both lungs. If a greater amount of blood should go through this compressed lung, a considerable deficit in the oxygen saturation would result, such as is present after plugging of the main bronchus of one lung, leaving the circulatory conditions in this lung intact (Le Blanc).

From experiments, Bruns [27] concluded that the capillaries become contracted primarily because of a reflex initiated by the lowered gaseous

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24. Cloetta, M.: Eine neue Methodik zur Untersuchung der Lungenzirkulation, Arch. f. exper. Path. & Pharm. **69**:147, 1910; Beiträge zur Physiologie und Pathologie der Lungenzirkulation und deren Bedeutung für die intrathorakale Chirurgie, Arch. f. klin. Chir. **97**:835, 1912. Cloetta and Stäubli, C.: Beiträge zur experimentellen Pathologie der Lungenzirkulation, Arch. f. exper. Path. & Pharm. **84**:317, 1919.

25. Anderes, E., and Cloetta, M.: Eine weitere Methode zur Prüfung der Lungenzirkulation, Arch. f. exper. Path. u. Pharm. **79**:291, 1916.

26. Le Blanc, E.: Respiratorischer Gasaustausch und Lungendurchblutung unter normalen und kranken Zuständen der Atmungsorgane, Beitr. z. Klin. d. Tuberk. **50**:21-95, 1922.

27. Bruns, O.: Ueber Folgezustände des einseitigen Pneumothorax, Beitr. z. klin. d. Tuberk **10**, 1909; Untersuchungen über den Blutgehalt und die Zirkulation in den Lungen bei normal ausgedehnten Lungen, bei offenem, einfach geschlossenem und Ueberdruckpneumothorax, München. med. Wchnschr. No. 22, p. 1252, 1912; Die Blutzirkulation in atmenden und funktionell ausgeschalteten Lungengebieten, Deutsch. med. Wchnsch. No. 39, 1912, München. med. Wchnschr. No. 40, p. 2194, 1912; Ueber die Blutzirkulation in der atelectatischen Lunge, Deutsch. Arch. f. klin. Med. **108**:469, 1912; Die Blutzirkulation in atmenden und atelektatischen Lungen, Deutsch. med. Wchnschr. No. 3, p. 101, 1913; Ueber die praktische Bedeutung der Zirkulationsstörung durch einseitigen Lungenkollaps bei therapeutischen Eingriffen and der Lunge, Beitr. z. Klin. d. Tuberk. **29**:253, 1913.

exchange in the alveoli, as demonstrated by Lohman and Müller.[28] This stage of contraction is followed by a period of relaxation. All the capillaries become dilated. An increased permeability of their wall is noted. A resultant edema is counteracted at the beginning by an increased lymph flow. This was demonstrated experimentally by Shingu,[29] Brauer,[30], Bruns [27] and Kistler.[31] A certain stasis persists. This chronic stasis resulting from an altered circulation acts as an irritant on the connective tissue in the wall of the alveolar sacs and atria and gives rise to a fibrous tissue formation (von Muralt [32]). Grätz [33] noticed this new tissue especially around the blood vessels and the bronchi; i. e., where we normally find connective tissue, which in the presence of a chronic stasis (edema) receives a new stimulation. This fibrous tissue developing as a result of a reaction, is generally found in parenchymatous organs of the body, as a late sequence of any chronic congestion (as in the liver or the kidney). The same condition in the subcutaneous tissue is called elephantiasis.

In a diseased lung, a second factor is active, the chemical irritation by the toxins from the zone of infection, from an altered cell metabolism and the metabolism of the micro-organisms. As pointed out by Brauer and Friedrich [18] these exotoxins and endotoxins are present in a greater quantity when the lung is collapsed. In the presence of a chronic stasis, their irritative action becomes more pronounced. This gives rise to a fibrous tissue formation around the areas of infection, wrapping them up in a thick sheath of connective tissue, and suppressing in this way any vicious exchange between the focus and the organism. The bacteria are doomed by increasingly unfavorable living conditions, the focus becoming at first clinically silent. Later on, as the repair process advances, healing occurs. The action of the toxins on the newly formed connective tissue is particularly conspicuous in cases of tuberculosis.

As shown by Grätz,[33] the areas of pathologic change enveloped in this fibrous tissue show no tendency to caseous breakdown. Calcifica-

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28. Lohmann and Müller: Ueber Durchblutung der Lungen in verschiedenen Dehnungszuständen, Sitzungsb. d. Gesellsch. z. Beförd. d. ges. Naturw. zu Marburg, 1913, No. 4.

29. Shingu: Beiträge z. Physiologie des künstlichen Pneumothorax und seine Wirkung auf die Lungentuberkulose, Beitr. z. Klin. d. Tuberk. **11,** 1910.

30. Brauer, L.: Die operative Beeinflussung einseitiger Lungenphthise durch totale Brustwandmobilisierung und Lungenentspannung, Arch. f. klin. Chir. **87**:647, 1908.

31. Kistler: Beitrag zur pathologischen Anatomie des künstlichen Pneumothorax, Beitr. z. Klin. d. Tuberk. **19**:459, 1911.

32. Von Muralt, A.: Die Behandlung schwerer einseitiger Lungentuberkulose mittelskünstlischem Pneumothorax, München. med. Wchnschr. **56**:2561, 1919.

33. Grätz: Der Einfluss des künstlichen Pneumothorax auf die Lungentuberkulose, Beitr. z. Klin. d. Tuberk. **10,** 1909.

tion is frequently met with. This process necessitates from two to three years. For a long time even then, these areas of infection remain merely inactive. Any greater mechanical traumatism may break up this fibrous envelop, rendering the focus active again. Therefore, in any lung healed clinically by collapse therapy, a certain danger of relapse is always present for a variable length of time, necessitating special precautions in the habits of living of these patients. As the years pass, the danger diminishes, but it is still present. We never know how reliable the fibrous covering around the former foci of infection is. Thus, the activity of these patients is hampered and their industrial efficiency lowered.

Artificial pneumothorax therapy, pneumolysis and extrapleural thoracoplasty, the standard operations of today for advanced unilateral lung tuberculosis, bring the lung to a functional rest by *indirect* action. A compressing agent (gas, plombage) is interposed between the rigid chest wall and the lung, causing a collapse of the organ. Another method of collapsing the lung is by mobilization of the chest wall by multiple, more or less extensive rib resection. The chronic stasis in the collapsed lung gives rise to a fibrosis, and when combined with general hygienic-dietetic measures, causes permanent arrest of advanced unilateral lung tuberculosis after from two to several years. During this treatment, the patient is more or less disabled. Special regulations in suitable climatic surroundings are necessary in most of the cases to guarantee the results claimed by the promotors of this treatment. The general resistance has to be raised in order to enable the body to combat the infection with success. In thoracoplasty, the same considerations form the basis of any successful treatment. The operation is only a subsidiary procedure to a thorough dietetic-climatic regimen. Deformity of the thorax and scoliosis of the spine cannot be omitted in enumerating the late effects of thoracoplasty. This holds true especially for the method of Sauerbruch. Brauer's subscapular-paravertebral resection, it is claimed, avoids this complication.

This essay may suggest the possibility of shortening the time for cure by employment of methods which force the lung to a physiologic rest by direct action, an extensive fibrosis of the organ thus being secured. This would assure a shorter period of invalidism in a disease which is of great importance because of its frequency among all the classes of society. Avoidance of a late thorax deformity is a point not to be neglected. In using these directly acting methods as a preliminary procedure to adapt one lung to the whole respiratory function, we may be able to diminish the dangers of a subsequent radical operative procedure, such as pneumectomy. One lung would gradually take over

the whole respiratory function. The extirpation of the diseased side would be a lesser shock than in a one-stage operation on these patients, emaciated by a long illness.

D. Directly Acting Methods of Putting the Lung to a Physiologic Rest.—By *direct action* a diseased lung can be put to a physiologic rest in the following ways:

1. By ligation of the pulmonary artery, which carries the venous blood to be arterialized in the lung.

2. By plugging of the main bronchus (fascia: Halsted-Crowe), keeping away any air from the lung, making an air exchange impossibie.

3. By partial occlusion of the pulmonary veins, a procedure rather effective because of the marked stasis resulting, with fibrosis arising from the chronic passive congestion, analogous to that encountered in organic heart lesions.

1. Ligation of pulmonary artery.—Küttner [34] was the first to follow the early changes in dogs after ligation of the pulmonary artery. Bruns [35] and Sauerbruch [36] repeated these experiments on a larger scale, observing the animals during a longer period of time. After three months, they noticed a marked fibrosis in the side operated on, with complete obliteration of the pleural cavity and considerable thickening of the pulmonary pleura. The shrinkage of the lung was remarkable, with deformity of the thorax. Kawamura [37] arrived at similar conclusions after experiments on rabbits and dogs. W. Meyer [38] and Sauerbruch [39] applied these findings to the clinic and ligated the pulmonary artery in cases of bronchiectasis. The result was a partial success.

For clinical work along this line, Schumacher's [40] studies on the cadaver are helpful. He brought out certain details in the topography

34. Küttner: Beitrag zur Kenntnis der Kreislaufverhältnisse der Säugetierlunge, Virchows Arch. f. path. Anat. **73**:476, 1878.

35. Bruns, O., and Sauerbruch, F.: Die künstliche Erzeugung von Lungenschrumpfung durch Unterbindung von Aesten der Pulmonalarterie, Mitt. Grenzgeb. Med. und Chir. **23**:343, 1911.

36. Sauerbruch, F.: Die Unterbindung von Pulmonalarterienästen zur Erzeugung von Lungenschrumpfung, Arch. f. klin. Chir. **95**:536, 1911; Deutsch. Ztschr. f. Chir. **125**:373, 1913.

37. Kawamura, K.: Ueber die künstliche Erzeugung von Lungenschrumpfung durch Unterbindung der Pulmonalarterienäste und den Einfluss derselben auf die Tuberkulose, Deutsch. Ztschr. f. Chir. **125**:373, 1913.

38. Meyer, W.: The Surgery of the Pulmonary Artery, Ann. Surg. **32**:189, 1913.

39. Sauerbruch, F.: Die Bronchiectasien, 3me congrès soc. intern. de chir., Bruxelles, 1911 (reprint).

40. Schumacher, E. D.: Die Unterbindung von Pulmonalarterienästen zur Erzeugung von Lungenschrumpfung, Arch. f. klin. Chir. **95**:536, 1911.

of the different structures at the hilum. Sauerbruch used the ligation in fourteen cases of bronchiectasis, and four times in the presence of new growths. An extensive fibrosis and retraction of the side operated on resulted. v. Voornveld [41] saw this operation performed in one case of bronchiectasis and in one case of advanced unilateral tuberculosis complicated by an abscess in the lower lobe on the same side. The complete cure of both patients within a relatively short time, without any subsequent infirmity (chest deformity, diminished physical strength) justifies a report of these cases, illustrating the accuracy of this method if applied to properly selected cases.

Case 1.—Miss M. K., Odessa, was in Davos in August, 1912, because of bronchiectasis of the right lower lobe. For two years, she had remittent fever. No tubercle bacilli were found in the sputum. The Wassermann reaction was negative. September 12, Professor Wilms ligated the lower branch of the right pulmonary artery. The patient had no immediate or late discomfort from the procedure itself. She made an uneventful recovery. In December, 1912, she was afebrile and there was practically no expectoration. In July, 1914, Dr. v. Voornveld received word that the patient felt perfectly well; and was free from fever and expectoration.

Case 2.—P. J. S., engineer, India, aged 35, in May, 1910, was a victim of an automobile accident. No objective findings of any injury could be made out; but since that time the patient had had fever, accompanied by an unproductive cough. His condition was growing worse. In November, 1910, he had a hemoptysis, and came to Davos seeking medical advice.

In May, 1911, examination by Dr. v. Voornveld revealed that the patient, who was emaciated, had an infiltration of the right upper lobe. A dull area over the right lobe was explained as resulting from an exudative pleurisy. The sputum contained tubercle bacilli. The temperature fluctuated about 38 C. (100.4 F.). In Davos, the tuberculous process improved, but a bronchitis persisted, and a change of climate was advised. In June, 1911, the patient went to San Remo (Italy), and in March, 1912, Dr. v. Voornveld was called to San Remo in consultation as the patient was growing worse. He always had a high fever. On the right side, a large exudate was present, and there was copious expectoration, the sputum containing tubercle bacilli. Dr. v. Voornveld made a diagnosis of tropical liver abscess, ruptured into the right lung at the time of the automobile accident, a tuberculous process present for years in the right upper lobe being thus activated. This process became inactive during the patient's stay in Davos, but was now active again. Dr. v. Voornveld suggested that the right pulmonary artery be ligated in one stage, and the abscess be opened in a second operation.

June 5, 1912, Professor Wilms withdrew 700 c.c. of serous fluid from the right chest by thoracocentesis. The patient felt much better.

June 14, the right pulmonary artery was ligated through a posterior approach. Involuntarily, Professor Wilms opened at the same time a huge abscess of the lower lobe. The patient made an uneventful recovery. Three weeks after the operation, he was out of bed. The temperature was slightly elevated in the

41. Personal communication.

evening (37.5 C., or 99.5 F.). He coughed three or four times a day. The abscess cavity drained for one month; then subsided within a short time, and closed by granulation. The patient returned to India and regained his health. He is still active as an engineer, and is enjoying perfect health.

These two cases demonstrate that ligation gives a complete clinical cure, not necessitating thoracoplasty, within a relatively short time, especially when compared to the palliative procedures hitherto used for these serious conditions. In cases of chronic tuberculosis without complicating factors, such as an abscess or bronchiectasis, ligation has never been used. The extrapleural thoracoplasty was found so satisfactory that no improvement of the technic by another procedure was thought of. In the two cases reported, no deformity of the thorax resulted as a late effect. This proves that ligation alone is sufficient to secure permanent cure in these lung conditions, without the chest deformity resulting from thoracoplastic procedures.

2. Plugging of the main bronchus. This procedure was originated by Dr. Halsted and tested by him and Dr. Crowe [42] in a series of experiments on dogs. Fascia was used. A marked shrinking of the lung resulted, with a deformity of the chest wall. The bronchi became dilated and filled with a homogenous gelatinous substance. The lung tissue between these bronchi was fibrosed.

After the main bronchus has been plugged, the remaining air in the alveoli is gradually absorbed. Primarily, the blood vessels in the alveolar wall enlarge as a result of the lowering of the intra-alveolar pressure, and become engorged and tortuous. Stasis follows, with consecutive, apparently increasing fibrosis. This dilation of the blood vessels resulting from the collapse of the alveoli is accompanied by a normal blood flow through this plugged lung, as demonstrated by Le Blanc [26] in a series of oxygen-saturation determinations in the systemic blood. A considerable deficit was always present owing to the great amount of nonarterialized blood passing through the plugged lung. As the bronchi dilated and became filled with this homogenous gelatinous mass, the alveoli were distended; the blood vessels became smaller, and fibrosis became apparent, owing to the conglomeration of the alveolar walls. This was manifest in a clinical observation of Rohmer and Borchardt,[43] in which the main bronchus of one lung was obliterated by a scar, probably due to syphilis. If a pneumothorax persists after the plugging, performed through transpleural approach,

42. Schlaepfer, Karl: Fibrosis of the Lung Following Ligation of the Pulmonary Artery Combined with Phrenicotomy and Following Partial Occlusion of the Pulmonary Veins, Arch. Surg. **6**:358 (Jan.) 1923 (Pt. 2).

43. Rohmer and Borchardt: Ein Fall von Verschluss des Hauptbronchus mit Lungenschrumpfung, Deutsch. Arch. f. klin. Med. **59**:585, 1897.

the fibrous changes are partly the result of the pneumothorax. As the bronchi are infected in all clinical cases in which the plugging method might be thought of, it is of no practical value.

3. Partial occlusion of the pulmonary veins. When performing a partial occlusion of the pulmonary veins, we create the condition encountered in certain heart lesions. The clinical observation of Rokitanski that heart lesions exclude lung tuberculosis was restricted later by Fräntzel and Eichhorst [44] to lesions of the left heart. Dagrève [45] and Tripier claimed that hypertrophy of the left ventricle resulting from a compensated organic heart lesion excludes tuberculosis. Romberg explained this immunity by the stasis causing an enlargement of the capillaries, thus rendering a hematogenous infection more difficult. The stasis resulting in a chronic passive congestion with subsequent fibrosis formed the anatomic basis of this clinical observation. Lesions of the right heart causing a diminished blood supply of the lung predispose to tuberculosis. Restriction of the blood supply in the apex (Freund) by constriction from the first rib favors an infection. Tiegel,[46] in 1911, with silver wire, partially occluded the pulmonary veins in rabbits and dogs. The resulting fibrous tissue proved very resistant to any tuberculous infection. When injecting pure cultures of tubercle bacilli in animals previously operated on in this way on one side, a striking difference was noted in the two lungs. The side which was not operated on was filled with disseminated tubercles. On the side of the partial occlusion, only a few tubercles were found. These findings were later confirmed by Schepelmann.[47]

4. Ligation of bronchial artery. Ligation of the bronchial artery, as proposed by Bruns and Sauerbruch,[35] means blocking of the main nutritive blood vessel to the lung, a procedure interfering directly with the vitality of this parenchymatous organ. Arising from the aortic arch or an upper intercostal artery, the bronchial artery is purely nutritive. By its ligation, a condition is created contrary to any principle applicable to surgical measures for disease of the lung. For therapeutic purposes, such a procedure should never be considered.

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44. Johanne, Otto: Das Ausschliessungsverhältnis zwischen Herzklappenfehler und Lungenschwindsucht, Virchows Arch. f. path. Anat. **144**:159, 1896.

45. Dagrève, M.: Contribution à l'étude de la tuberculose pulmonaire au cours des affections valvulaires du coeur gauche, Rev. internat. de la tuberc. **18,** No. 13 (Sept.) 1918.

46. Tiegel, M.: Experimentelle Studien über Lungen- u. Thoraxchirurgie, Mitt. Grenzgeb. Med. & Chir. **3**:789, 1907 (Supplement); Operative Lungenstauung und deren Einfluss auf die Tuberkulose, Arch. f. klin. Chir. **95**:811, 1911.

47. Schepelmann, E.: Tierexperimente zur Lungenchirurgie, Arch. f. klin. Chir. **100**:985, 1913.

5. Auxiliary procedures. Several auxiliary procedures were suggested by different men in an endeavor to put the lung in complete physiologic rest. These suggestions may be discussed in the different procedures as supplementary.

(*a*) Extrapleural thoracoplasty. This was devised by Sauerbruch as supplementary in cases in which the shrinking of the chest after ligation of the pulmonary artery was hampered by adhesions. The report of the cases of Dr. van Voornveld proves that we can deal with extensive tuberculous lesions of the lung with large cavities by ligation alone, thus avoiding a permanent deformity of the thorax, which may be later the source of great discomfort to the patient.

(*b*) Plombierung (plugging). For lesions in the upper lobe which do not yield to a primary thoracoplasty, fat (Tuffier),[15] paraffin (Baer)[16] and pectoral muscle (Kirschner,[48] Archibald[49]) were proposed as compressing agents on cavities and infiltrations. These materials can also be used in other parts of the chest when an unusual effort is necessary to collapse a cavity.

(*c*) The resection of the phrenic nerve (phrenicotomy). This, recently improved by a subsequent evulsion of the distal part (exairesis: Felix[50]), was first proposed by Stuertz[51] and later by Sauerbruch.[52] It helps greatly to diminish the function of one lung. Recently, Sauerbruch[53] employed phrenicotomy for diagnostic purposes preliminary to thoracoplasty, to find out whether the healthy lung was able to assume the function of the diseased side. Goetze[54] and Frisch[55] used phrenic-

48. Kirschner: Verhandl. d. Deutsch. Gesellsch. f. Chir. **44**:260, 1920.

49. Archibald, E.: Surgical Treatment of Unilateral Tuberculosis, Ann. Surg. **77**:652 (June) 1923.

50. Felix, W.: Anatomische und klinische Untersuchungen über den Phrenicus und über seine Zwerchfellinnervation, Deutsch. Ztschr. f. Chir. **171**: 283-397, 1922.

51. Stuertz: Künstliche Zwerchfellähmung bei chronischer einseitiger Lungentuberkulose, Deutsch. med. Wchnschr. No. 48, 1911, p. 2224; Experiment. Beitrag. zur Zwerchfellbewegung nach einseitiger Phrenicusdurchtrennung, Deutsch. med. Wchnschr. No. 19, 1912, p. 897; Der künstliche Pneumothorax und die operative Behandlung schwerer Lungentuberkulose, München. med. Wchnschr. No. 44, 1913, p. 2485.

52. Sauerbruch, F.: Die Beeinflussung von Lungenerkrankungen durch künstliche Lähmung des Zwerchfelles (Phrenikotomie), München. med. Wchnschr. **60**:625, 1913.

53. Sauerbruch, F.: Kritische Bemerkungen zur Behandlung von Lungenerkrankungen durch künstliche Lähmung des Zwerchfelles, München. med. Wchnschr. **70**:693 (June 1) 1923.

54. Goetze, O.: Die radikale Phrenicotomie als selbständiger therapeutischer Eingriff bei einseitiger Lungenphthise, Klin. Wchnschr. **50**:1496 (July) 1922.

55. Frisch, V.: Zur Frage der Phrenicotomie als Therapie der Lungentuberkulose, Wien. klin. Wchnschr. **2**:72 (Jan. 8) 1923.

otomy alone in cases of unilateral lung tuberculosis, presenting particular involvement of the lower lobe, with great satisfaction. Schepelmann [56] proposed phrenictomy for early cases of lung tuberculosis. Walter [57] and Heuer [58] made extensive roentgen-ray studies on the physiology of the two sides of the diaphragm and of the lung following phrenicotomy. In an exhaustive paper, Felix [50] discussed the anatomy and physiology of the phrenic nerve. Lange's [59] paper on the same subject is interesting for the great number of clinical observations made after this operation.

(d) Section of intercostal nerves. Warstat (Friedrich) saw a contraction of the rigid chest wall after resection of the intercostal nerves of one side, a procedure which will never be very effective.

II. EXPERIMENTAL DATA

A. *Rabbits.*—In my experiments, which will be reviewed in detail, I intended to ascertain the findings of former workers along the same line, and to obtain sufficient anatomic-physiologic data following well defined operations within the chest cavity. These findings may form the basis for subsequent clinical work including studies such as blood, gas and alveolar air analyses. The few casualties urge one, as Brauer [60] says, to widen the clinical experience along this special line of thoracic surgery.

A first series of experiments was performed on rabbits. Later on, dogs were used because rabbits would not tolerate the pressure changes occurring in the right side of the heart after ligation of the pulmonary artery. Drinker, Peabody and Blumgardt [61] were able to demonstrate on dogs that, following partial occlusion of the pulmonary artery in the center of its bifurcation an elevation of the pressure for only a few millimeters caused sudden death. This might explain the high mortality in our rabbit series. Two of our rabbits that died during the operation showed a markedly enlarged thymus. Lowson,[62] Schepelmann [47]

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56. Schepelmann, E. Einseitige Lungenimmobilisierung durch Phrenicusresektion, Arch. f. klin. Chir. **100**:985, 1913; München. med. Wchnschr. **60**: 490, 1913.

57. Walter, H.: Röntgenologische Untersuchungen über die Wirkung der Phrenikotomie, Bruns Beitr. z. klin. Chir. **90**:358, 1914.

58. Heuer: Personal communication with the author.

59. Lange, K.: Ueber pathologische und therapeutische Zwerchfellähmung, Deutsch. Ztschr. f. Chir. **169**:159, 1922.

60. Brauer, Schröder and Blumenfeld: Handb. d. Tuberk. **3**, Die operative Behandlung der Lungentuberkulose, Leipzig, 1919, **3**:171.

61. Drinker, C. K.; Peabody, F. W., and Blumgardt, H. L.: The Effect of Pulmonary Congestion on the Ventilation of the Lungs, J. Exper. Med. **35**:77 (Jan.) 1922.

62. Lowson, C. M.: A Case of Pneumectomy, Brit. M. J. 1893, p. 1152.

and Tiegel [46] do not mention such an experience in analogous operations. The ill effect of the open pneumothorax was overcome by using intratracheal ether insufflation anesthesia. When using infiltration anesthesia (procain 1:300) for the chest wall, inducing intratracheal anesthesia only from the moment the pleural cavity was opened, the

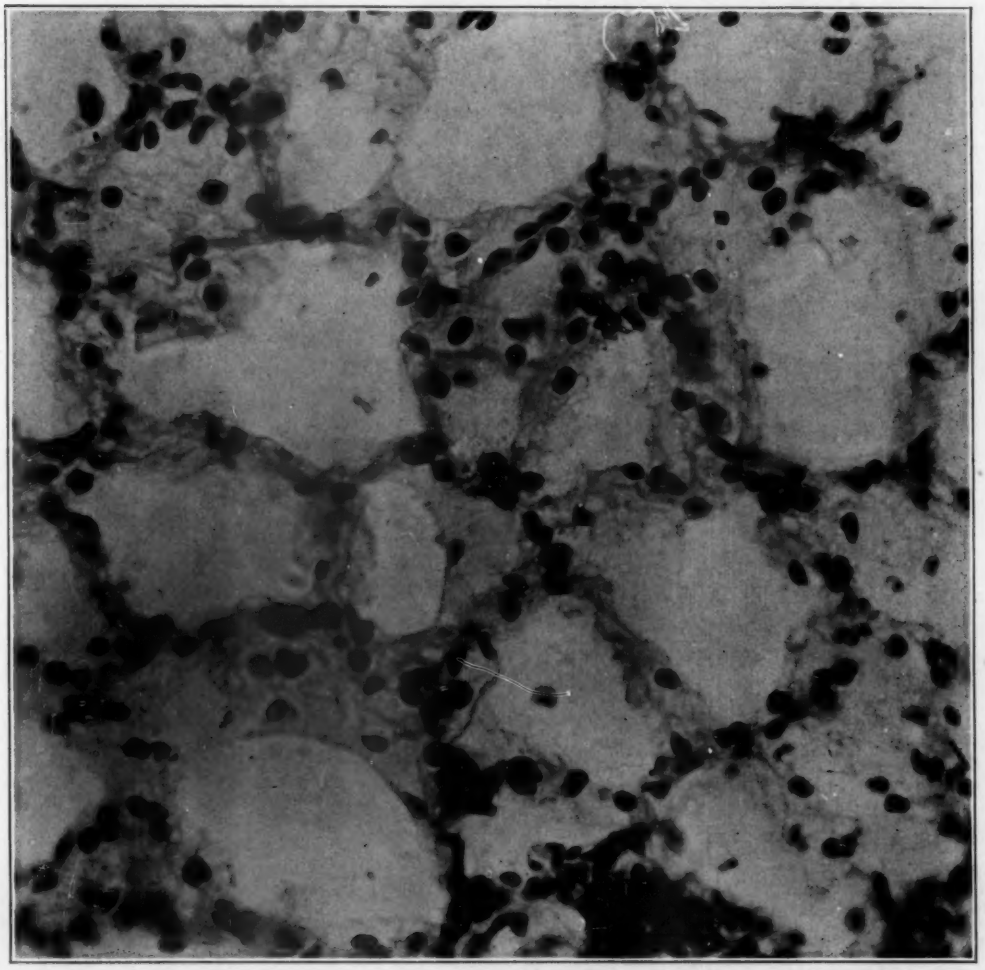

Fig. 1.—Photomicrograph of normal rabbit lung. The alveolar septa are outlined by cubical epithelial cells. No spindle cells are visible. The capillaries are not dilated. The alveolar spaces are free.

operative shock was greatly diminished. The recovery of the animals was much quicker. On dogs, ether given intratracheally was taken very well.

Anatomic data: Each rabbit lung is divided into three lobes, an upper, a middle and a lower, separated from each other by variable

deep fissures. On the left side, the upper lobe is generally imperfectly developed (Bensley).[63] The inferior right lobe forms two separate lobules: a medial one, called the pericardial or mediastinal lobe, which passes behind the inferior vena cava to the left side, and a major, lateral lobule. The mediastinum, which separates the two lungs, forms anteriorly a very thin membrane, which yields easily to slight pressure changes. On microscopic section, the rabbit lung is seen to have the alveolar walls outlined with cubical cells, with large amounts of cytoplasm, and with a central ovoid nucleus. Crosssections through blood vessels change the uniform picture (Fig. 1).

Technic: The routine technic used in all operations (on rabbits and dogs) was the following: The left anterior chest side was shaved over a large area, the fourth and fifth intercostal spaces, the incision being in the center. This area was disinfected with alcohol and tincture of iodin (7.5 per cent.). An incision of sufficient length was deepened dowr into the pleural cavity and spread widely with an automatic retractor, exposing the hilum region, especially after the lung is pulled into the wound toward the lateral angle of the incision. The topography of the hilum region may be described thus: In a frontal plane, the pulmonary veins are the most ventral and caudad. There are generally three veins, one for each lobe. More dorsally, crossing on the posterior aspect of the upper pulmonary vein, the pulmonary artery passes to the lung, recognizable by its larger size, thicker wall and its rhythmic pulsation. Behind the artery, rather caudad, is the main bronchus. After the vessel was liberated from its pleural covering, the artery was ligated twice with silk, and cut between the ligatures. The phrenic nerve was resected at the upper end of the pericardium for a distance of 2 cm. In some cases, the nerve was crushed very extensively with an artery forceps for the same distance. Before the chest wall was closed, great care was taken not to overlook any oozing. Pericostal stitches of heavy silk were applied; the lung was blown up to its maximum, and the stitches were then tied. The muscles were sutured in two rows; the subcutaneous tissue was sutured in one, and a continuous silk-skin suture completed the tight closure of the thoracic wall. The use of silk gave in all instances the same result as it had for years, irritating the tissues less than catgut.

Postoperative course: The ligature of the pulmonary artery caused no visible changes in the animals. No alteration of the respiration rate or of the heart beat was noticed, the findings conforming to those in Underhill's analogous investigations. Underhill[64] found only a rise in

63. Bensley, B. T.: Practical Anatomy of the Rabbit, Ed. 3, Philadelphia, P. Blakiston's Son & Co., 1923.

64. Underhill, S. W. F.: An Investigation Into the Circulation Through the Lungs, Brit. M. J. **2**:779 (Nov. 12) 1921.

blood pressure in the remaining pulmonary artery immediately after ligation, varying between 25 and 60 (usually 40) per cent. of the original pressure. This higher pressure persisted for from twenty-five to forty minutes, and then returned gradually to normal. This is probably the time necessary for dilatation of all the arterioles and capillaries of the intact lung, the peripheral resistance being thus diminished and the blood flow facilitated through the one lung. Bruns and Sauerbruch [35] noticed after ligation a more or less marked dyspnea, of short duration, with diminishment of the rate of the heart beat. A deepening and acceleration of the rate of respiration accompanied this process. A few minutes later, the symptoms subsided. Kawamura [37] performed ligation on dogs without any objectively noticeable disturbances.

After the operation, when waking up from the effect of the anesthesia, the animals were less active, breathing faster than before, but deeper and thus causing better aeration of the one functioning lung. This was partly a result of the pain in the wound. It was variable in intensity and duration in the different animals. After from twenty-four to forty-eight hours, most of the animals looked normal. When phrenicotomy was performed, a persistent hiccup was often observed for days, becoming more marked when the animals were excited by visitors. Sometimes mucus tinged with blood was expectorated for the first two or three days. After two days (from the third to the fifth), the animals were just as active as before the operation and did not show any signs of postoperative weakness. They never showed signs of dyspnea, even after jumping around in the yard, or when barking loudly for a certain time. They were killed by ether. When under deep anesthesia, some formaldehyd (10 per cent.) was poured into the trachea. Before the thorax was opened, the trachea was clamped to prevent collapse of the lung.

The rabbits series consisted of nine animals, two of which died at the time of operation, immediately after the pulmonary artery was ligated, presumably as an ill-effect of the elevation of the pressure in the right side of the heart. The persistent thymus in both cases might account for the lowered resistance. The same rise of pressure is also probably responsible for death in men when the main stem of the pulmonary artery or the majority of main branches in both lungs are blocked by thrombi, as proved experimentally on dogs by Drinker and his co-workers. In one rabbit, the chest wound became infected and burst into the pleural cavity, transforming the whole side into a huge abscess enveloped in a thick fibrous capsule.

EXPERIMENTAL DATA

EXPERIMENT 1.—A medium sized rabbit, the semicircumference of whose chest was 11 cm. (both sides), was subjected to ligation of the left pulmonary artery, and resection of the phrenic nerve for a distance of 2 cm. There were

no changes in the respiration rate and heart beat. The animal recovered from the operation and sat in a corner. The next morning it was dead in the cage, ten hours after operation.

At necropsy, on inspiration the two sides were symmetrical, left diaphragm being at the same level on either side, but more flabby on the left. The trachea was clamped before the chest was opened. The right lung was retracted to a certain extent, and there was 3 c.c. of straw-colored fluid in the chest cavity. The lung was reddish and normally crepitant. In the left pleural cavity, there was 3 c.c. of blood. The lung, which was collapsed, was one-third the size of the right lung, and dark red. Adhesions to the chest wound were easily broken off. There were no other pleural adhesions. The left lung was much firmer in consistency. On section, the right side was moist. There was no escape of frothy fluid on the left. The right ventricle showed maximal dilatation, the left side of the heart was contracted. The thymus was persistent.

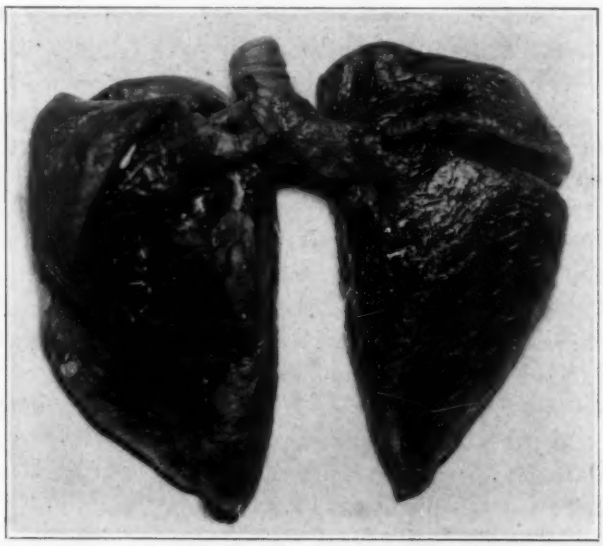

Fig. 2.—Rabbit lungs forty hours after ligation of the left pulmonary artery. There is no marked difference in the size of the two lungs.

Microscopic examination of the left side revealed that the alveolar septums were thickened because of tortuous, engorged blood vessels. There was some extravasation of blood into the alveolar spaces; others were empty. On the right side, there was moderate dilatation of the capillaries in the alveolar septums. The alveolar spaces were empty.

EXPERIMENT 2.—Medium-sized rabbit, semicircumference 13 cm. on either side, underwent ligation of the left pulmonary artery, with uneventful recovery. The animal, sitting in a corner, breathed faster than before the operation, but gave no other signs of dyspnea. It died suddenly twenty hours after operation.

At necropsy, the diaphragm on both sides was at the same level. When the right pleural cavity was opened, the right lung was found to be retracted somewhat. There was no free fluid in the pleural cavity. In the left pleural cavity, there was 2 c.c. of bloody fluid. The left lung was collapsed, dark red and

half the size of the right. The pleural surfaces were smooth, glistening and free. The left lung was firmer. The right side was red, and of normal consistency. On section through the left lung, there was extravasation from lung spaces, slightly frothy. The right side was moist, and there was frothy fluid as on the left. There was no enlargement of the right ventricle. The thymus was persistent.

Microscopically, same picture was noted as in Experiment 1.

EXPERIMENT 3.—A small rabbit, semicircumference 10.5 cm. on both sides, underwent ligation of the left pulmonary artery. Shortly after the operation, the animal was quite active. The following day, there were no signs of discomfort. The animal was found dead in his cage forty hours after operation.

At necropsy, the diaphragm was found at the same level on both sides. The right pleural cavity was free. In the left pleural cavity, there was 1 c.c. of bloody fluid. There were adhesions of the left lung on the mediastinal side, which were easily broken up. Both lungs were about the same size (Fig. 2). After removal, the right one contracted somewhat. The left lung remained the same size. It was bluish red, and much firmer in consistency. The left lung on section showed a frothy fluid. The right side was reddish gray and moist.

Microscopically, the left lung showed marked dilatation and tortuosity of the capillaries. The alveolar spaces were partly filled with red blood corpuscles. In some areas, dilatation of the capillaries was less marked; the alveolar lining was well preserved, and there was no pleural thickening (Fig. 3). On the right side, the alveolar spaces were in several areas dilated. The arterioles were generally enlarged; the capillaries, only in some areas. The alveolar spaces were free.

EXPERIMENT 4.—A medium-sized rabbit, semicircumference 12.5 cm. on each side, whose left pulmonary artery was reduced to half its size, and the phrenic nerve resected for a distance of 2 cm., suffered temporarily from very slow heart action after ligation. For twenty-four hours, the animal was rather drooping, but later became more lively. It was found dead in its cage forty hours after operation.

At necropsy, the diaphragm was at the same level on each side. There was no fluid in the pleural cavities, and there were no pleural adhesions. The right lung, somewhat collapsed, was red and normally crepitant. The left lung, which showed no pleural adhesions, was about the size of the right, bluish red, and felt much firmer than a normal lung. On section, there was a moderate amount of frothy fluid. No dilatation of the right side of the heart was noted.

Microscopically, on the left side the capillaries in the alveolar septums were dilated and tortuous. There was some epithelial desquamation, with red blood corpuscles present. In some areas, these changes were not so marked. On the right side, the alveoli were rather large, as compared with those of a normal lung. The blood vessels were somewhat prominent; but the capillaries were not dilated. There was some desquamation of epithelial cells.

EXPERIMENT 5.—A medium-sized rabbit, semicircumference 12 mm., whose left pulmonary artery was ligated in the usual way; made a quick recovery. On the following day, it was very active, but later became drowsy, and died on the fourth day of a double pneumonia. (A distemper epidemic was ravaging the kennels at that time.)

EXPERIMENT 6.—A medium-sized rabbit, semicircumference of the chest 12.5 cm. (equal on each side), whose left pulmonary artery was ligated, and the phrenic nerve resected for 1 cm., made a quick, uneventful recovery. On

the following day, it was as active as before the operation. Without signs of illness, it was found dead in its cage twenty days after operation.

At necropsy, examination revealed that the diaphragm was somewhat higher on the left side, and was less resistant than on the right side. When the right pleural cavity was opened, the lung contracted to a certain extent. There was no free fluid. The lung was red, and was normal in consistency. There was

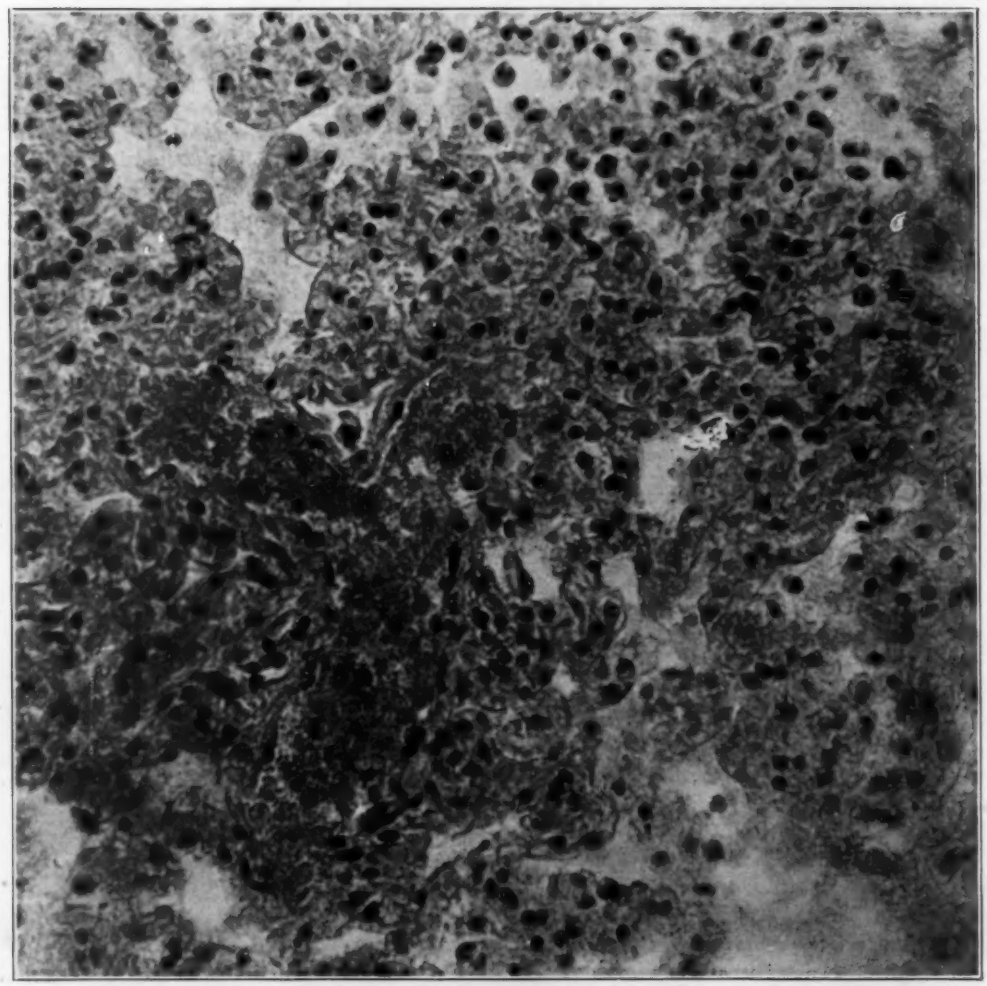

Fig. 3.—Photomicrograph of the lung on which ligation was performed forty hours after operation. There is marked dilatation of the smaller blood vessels and of the capillaries within the alveolar septa. The alveolar spaces are partly or completely filled with blood and with desquamated alveolar lining cells.

slight emphysema. On the left side, the lung formed a small hard mass in the left chest cavity, half the size of right, the mediastinal lobe of the right side filling out the space between the retracting left sided lung and the left side of

the diaphragm. The left lung (Fig. 4) was adherent on the mediastinal surface; on the costal side, it was free. The adhesions were fibrous. The cut surface was dry, dark purplish red and firm. The bronchi were dilated.

Microscopically: On the left side, all blood vessels and capillaries were markedly dilated. Strands of fibroblasts were seen growing from the perivascular and peribronchial tissue, invading alveolar septums, and sufficiently marked to cause trabeculation of the lung tissue (Fig. 5). There was fibrous tissue formation. The alveolar lining cells were still intact. In some areas, the elastic tissue layer of smaller blood vessels was hypertrophied. The larger bronchi were markedly dilated, and there was no noticeable thickening of the pulmonary pleura. On the right side, there were dilatation and slight tortuosity of the capillaries. The alveolar septums appeared prominent. The alveoli were somewhat dilated. The epithelial cells were flattened, but intact.

Fig. 4.—Rabbit lungs twenty days after ligation of the left pulmonary artery. The difference in size of the two lungs may be noted.

EXPERIMENT 7.—A medium-sized rabbit, semicircumference 12 cm., whose left pulmonary artery was ligated and phrenic nerve resected for 1 cm., made an uneventful recovery. There was no change in the heart rate or respiration. During the first week, the course was perfectly normal. The second week, an abscess in the scar of the chest wall was opened, and the wound was closed again. The abscess recurred. The abscess was drained twice, and on the second time, the rabbit died during the procedure, thirty-nine days after the ligature.

At necropsy, the whole left side of the chest was transformed into a caseous mass, enveloped in a leathery capsule of dense fibrous tissue. No remnant of the lung was seen. The trachea ended blindly in this mass. The left side of the chest was about one fifth smaller than the right. The right lung was normal in

consistency and on cut section. On microscopic examination, some dilated interalveolar arteries were revealed. The capillaries were not particularly dilated.

EXPERIMENT 8.—A medium-sized rabbit, semicircumference 13 cm., underwent ligation of the left pulmonary artery. The left phrenic nerve was cut, and silver clips were applied to the two ends of the nerve. The animal

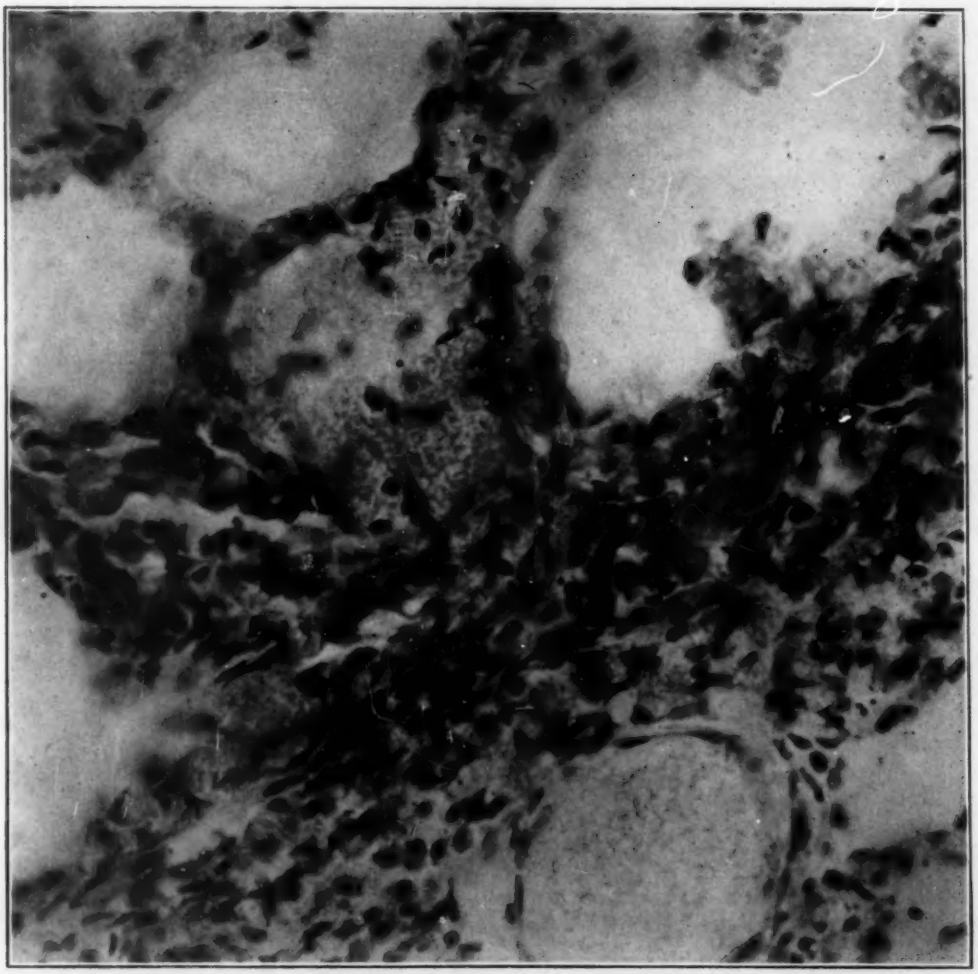

Fig. 5.—Photomicrograph of the lung which was operated on, twenty days thereafter. The smaller blood vessels and capillaries are markedly dilated. There are strands of fibroblasts (spindle cells) growing from the perivascular and peribronchial tissue and within the alveolar septa, causing a trabeculation.

recovered quickly. A small abscess underneath the skin, which developed in the second week, was excised, and healed by first intention. The rabbit was normal up to the time it was killed, 109 days after operation. Roentgen-ray

examination of the chest fifty-seven days after the operation (Fig. 6*b*) revealed marked displacement of the mediastinum and heart to the side (left) operated on, the two silver clips along the mediastinal pleura forming a good landmark for the changes. (Fig. 6*a* shows a normal rabbit chest.) There was no marked deformity of the chest. Even a scoliosis was doubtful. The upper part of the left lung was dark, owing to the presence of infiltrated tissue (stasis). The lower part was rather light, owing to the fact that the mediastinal lobe of the right lung was pushed over to the left side. A second roentgen-ray examination, 100 days after the operation (Fig. 6*c*), revealed about the same displacement. There was no further displacement of organs, and no difference in the level of the two diaphragms, even after 100 days.

At necropsy, no difference in the thorax was noted. The sides were equally prominent and the diaphragm on either side was at the same level. When the right pleural cavity was opened, the lung was somewhat retracted. There were no adhesions and no free fluid was found. The lung was red and normally crepitant. When the left pleural cavity was opened the left lung filled the upper and middle part of the left thoracic cavity. The visceral and parietal pleura was firmly attached by fibrinous adhesions on all sides. The right mediastinal lobe, which filled the space between the left lung and the diaphragm, was adherent to the diaphragm. The size of the two lungs is well shown in Figure 7. The left lung was composed mostly of necrotic cell detritus, filling the dilated main bronchus. The envelop was formed by thickened pleura. At some places, this covering was thicker, but it did not show any evidence of air.

On microscopic examination of the left side, the marked dilation of the main bronchus, lined with cylindrical epithelium, made it easy to follow the outline. The pleura and underlying lung tissue were converted into a dense fibrous structure (Fig. 8). The elastic tissue was relatively increased. In the right lung, the alevolar septums were thickened and straightened. There was marked dilatation of all the smaller blood vessels and capillaries (Fig. 9). There was no evidence of any fibrous tissue increase.

Summing up the findings in the rabbits series, we must remember that, even in clamping the trachea before opening the thorax, a certain collapse of the light red dilated intact lung occurred, due to its elasticity. The dark bluish, denser side, on which operation had been performed, with all signs of a marked stasis remained the same. Put in water, the intact side floated, the side operated on sank. Adhesions on the latter side were restricted to the mediastinal aspect in two and to the wound of operation in one of five cases. In two necropsies, ten and twenty hours after operation, showing great differences (from one third to one half) in the size of the two lungs, the ligated side was not fully expanded at the end of the operation, when the chest wound was closed. During the first week, the size of the two lungs did not vary greatly, the ligated side being filled with blood. The bluish red, denser ligated lung showed frothy fluid on section. On microscopic examination, the side operated on showed marked dilatation and tortuosity of all blood vessels and especially the capillaries within the alveolar septums. Some of the alveoli were filled with blood (diapedesis). Some alveolar spaces contained serous transudate; others were free. Desquamated alveolar

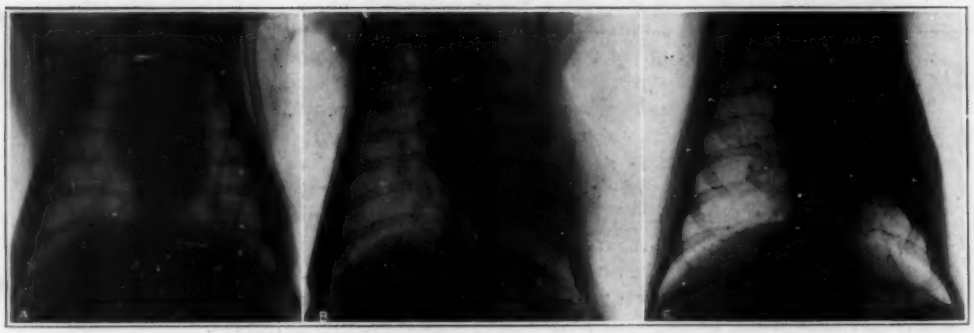

Fig. 6.—*A*, normal rabbit chest. The position of the mediastinum and the heart may be noted. *B*, rabbit chest fifty-seven days after ligation of the left pulmonary artery combined with resection of the phrenic nerve. Silverclips were applied to the phrenic. Displacement of the mediastinum and the heart toward the side of operation may be noted. Cloudiness of the lung area on the side of operation. The light area in the lower left resulted from the displacement of the right mediastinal lobe, interposed between the diaphragm and the left lung. *C*, same chest after 110 days. Displacement of the mediastinum is more marked. Gradual dilatation of the right mediastinal lobe caused an enlargement of the light area in the lower left region.

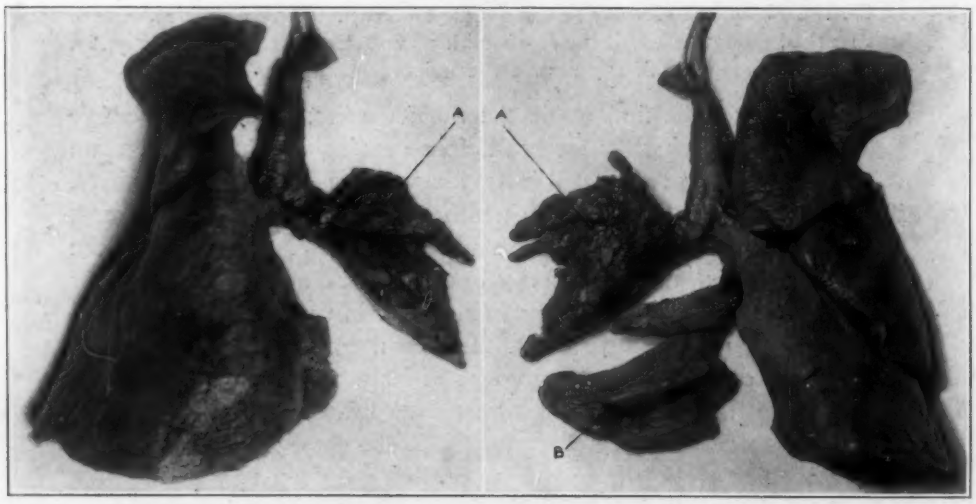

Fig. 7.—Rabbit lungs 109 days after ligation of the left pulmonary artery combined with phrenicotomy. Left, anterior aspect; right, posterior aspect. The small shrunken left lung may be noted. The right mediastinal lobe shows a compensatory dilatation. *a*, Shrunken left lung; *l*, right mediastinal lobe. (Compare Figure 9.)

lining cells were noticed. On the intact side, some dilatation of the smaller blood vessels and capillaries was conspicuous after three weeks. The difference in size of the two lungs was striking. The distended, emphysematous intact side, light red and of normal consistency and air content, pressed the side of ligation by displacing the mediastinum and

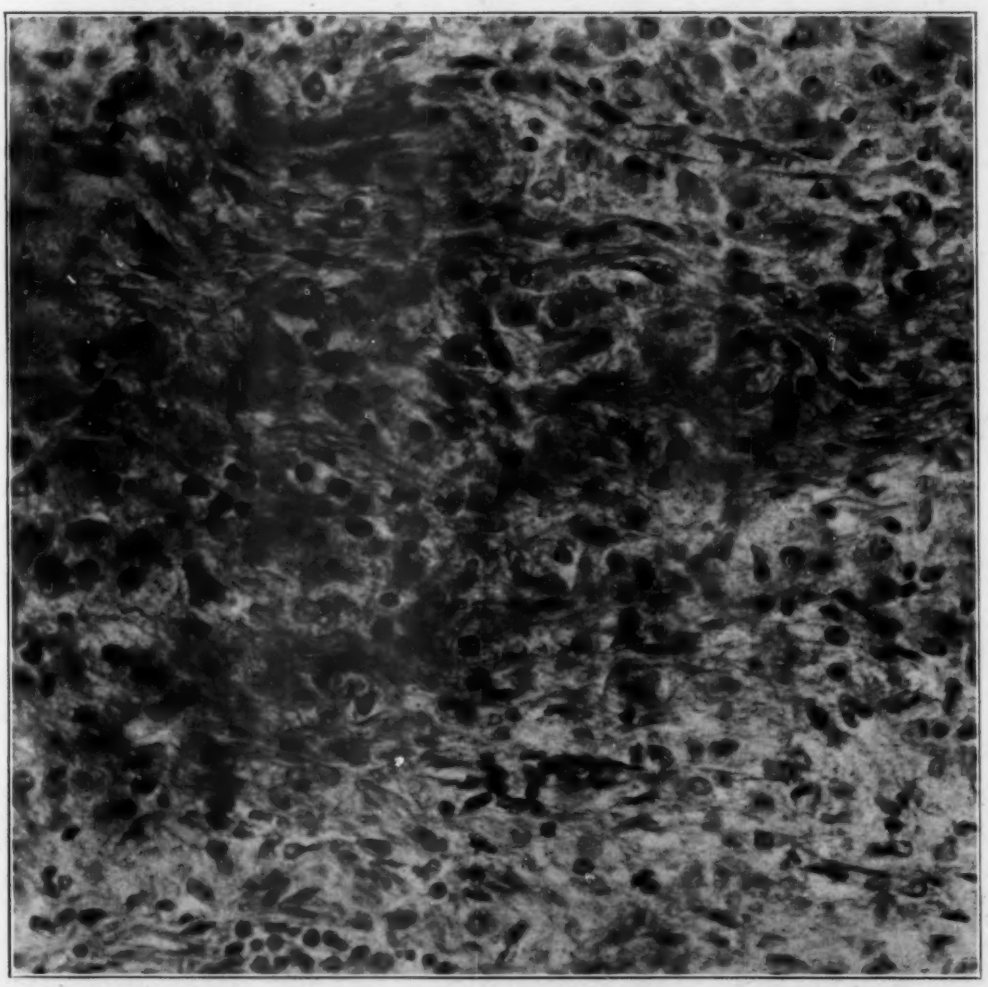

Fig. 8.—Photomicrograph through side of operation (109 days after ligation). There is connective tissue proliferation. No alveolar spaces are visible. The cubical cells with large cytoplasm are alveolar epithelial cells. Macrophages are present.

heart. The right mediastinal lobe extended behind the inferior vena cava to the left lateral chest wall. This contrasted markedly with the shrunken ligated side, one-half its size, bluish-red and of very firm con-

sistency. No thickening of the free pulmonary pleura could be made out. On this side, the air content was greatly reduced. Microscopically, tortuosity and dilatation of all blood vessels and capillaries gave a striking picture. Strands of fibrous tissue were spreading within the perivascular and peribronchial tissue, expanding the alveolar septums,

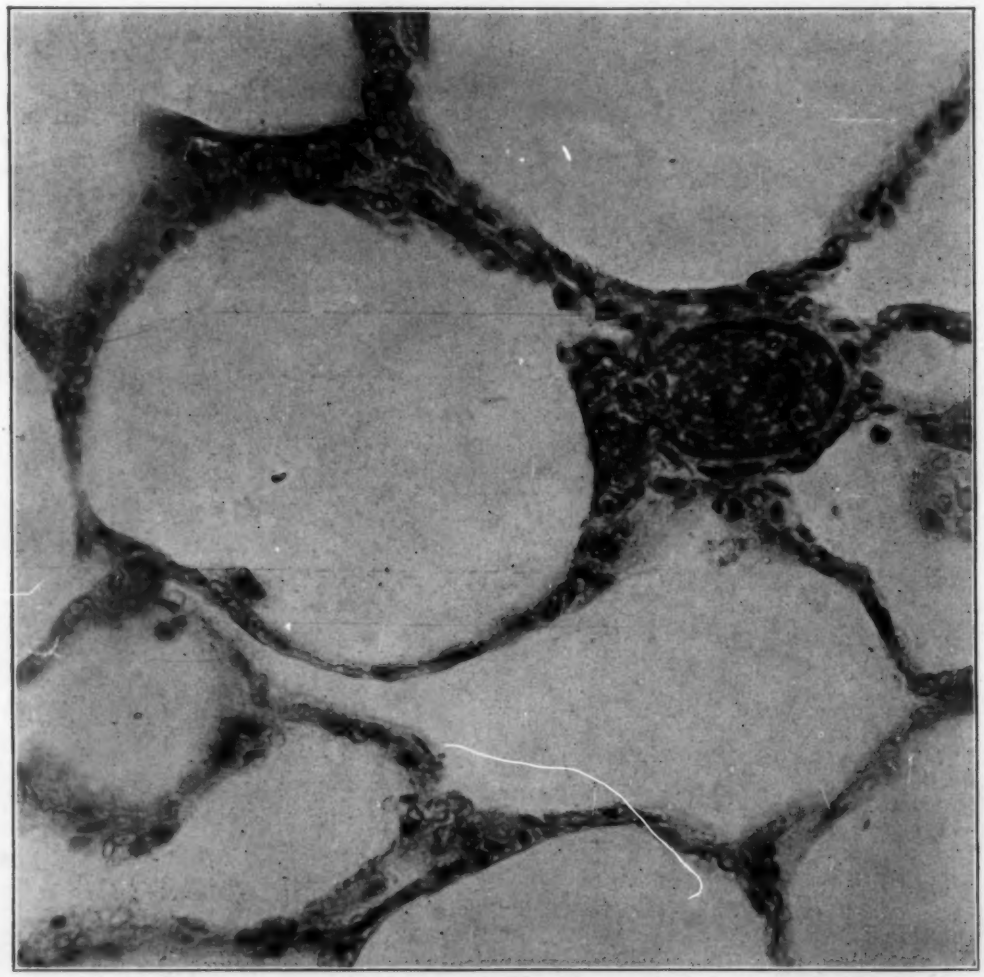

Fig. 9.—Intact side (109 days after ligation). The compensatory dilatation of the alveolar septa may be noted. Dilated smaller blood vessels and capillaries are visible. There is no connective tissue growth.

thus causing a trabeculation. These spindle-shaped cells became predominant; the cubical epithelial cells, rare. The elastic tissue (Weigert) was increased. The pulmonary pleura was not thickened, except in the liberated areas.

On the intact side, dilatation of all capillaries was conspicuous. Otherwise, it was the picture of a normal lung.

After three and a half months (109 days), a slight deformity of the side operated on was noticed. The shrunken left lung in the upper thoracic cavity was in contrast with the dilated right side extending over

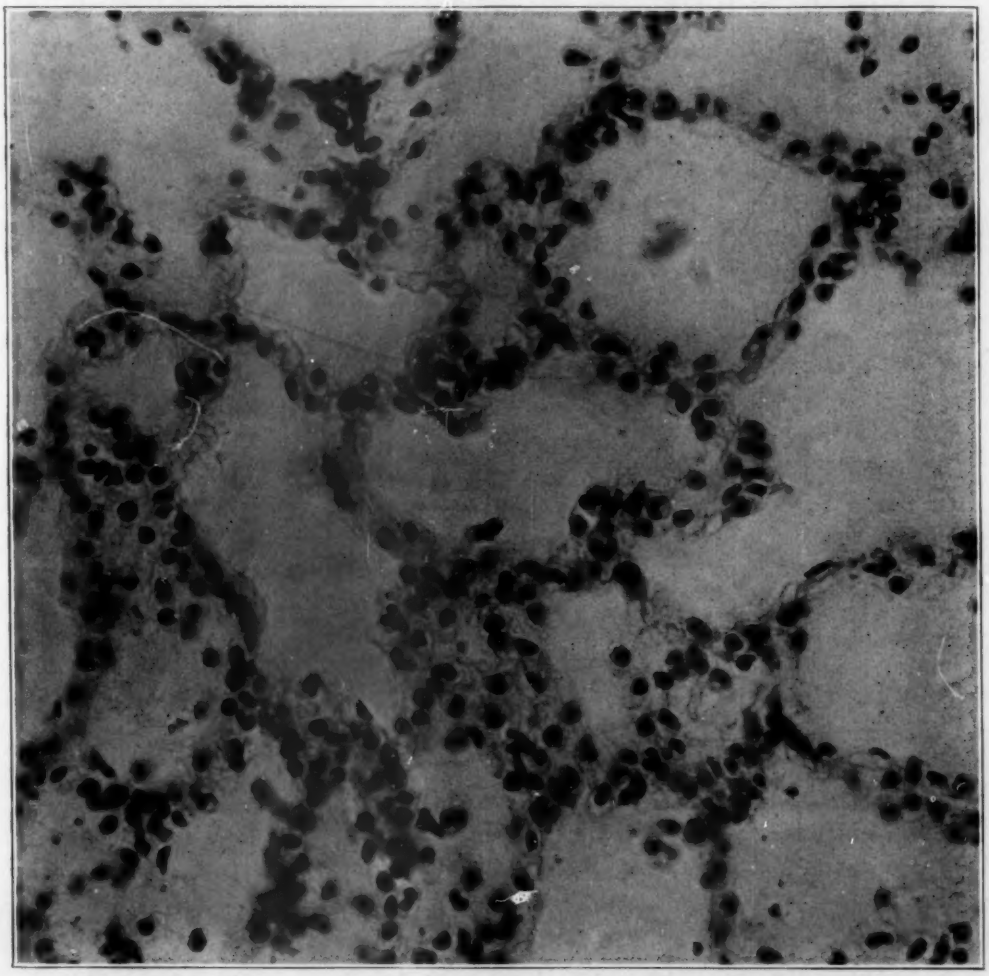

Fig. 10.—Photomicrograph of normal dog lung. The alveolar septa are lined with cuboidal epithelial cells. The capillaries are not dilated.

the midline to the left in the upper part and with its mediastinal lobe. The light red right side was emphysematous; the dark bluish shrunken left lung was embedded in dense adhesions. It was one half the size of the right side. The center formed by the enlarged main bronchus was

filled with cell detritus. In the wall under the thickened pleura, the lung tissue showed markedly dilated capillaries, surrounded by young fibrous tissue, dividing groups of alveolar spaces in lobules. The fibroblasts were the predominant cells in the alveolar septums. The elastic tissue (Weigert) was increased.

On the right side, a marked dilatation of the alveolar spaces, with stretching of their septums, was visible. All the blood vessels were dilated. No sign of fibrosis was demonstrable.

B. Dog Series.—Anatomic Data: The lung of the dog shows the same lobe formation as that of the rabbit (Ellenberger and Baum).[65] The separation between the upper and middle lobe is variable, so that they often are considered one lobe. The left upper lobe is often imperfectly developed. As in the rabbit (Bensley),[63] the division of the right lower lobe into a medial lobule, the pericardiac or mediastinal lobe, and a lateral part is remarkable, the topography of which is also here of great importance for the better understanding of the changes taking place after ligation of the pulmonary artery.

Microscopically, the lung of the dog is composed of a thin alveolar wall lined by cuboidal epithelial cells. Capillaries are practically invisible (Fig. 10).

Technic: This was the same as outlined in the rabbit series, intratracheal insufflation anesthesia being used throughout the series. Two different types of operation were performed: (1) ligation of the pulmonary artery, on the left side; (2) ligation of the left pulmonary artery combined with phrenicotomy, the nerve being resected for a distance of 2 cm. In some cases, the nerve was not cut, but thoroughly crushed for the same length.

Postoperative course: The dogs stood the operation very well, especially ligation alone. No immediate change in the respiration rate, heart action or pulse rate was noticed. In the first twenty-four hours, the dogs were naturally less active than before operation.

Ligation of the left pulmonary artery was performed on six dogs; but two experiments have to be discarded owing to the fact that one dog died of pleurisy acquired at the operation, and the other one died of distemper (bronchopneumonia, double).

EXPERIMENT 9.—A medium-sized dog, semicircumference 23.5 cm., whose left pulmonary artery was twice ligated with heavy white silk, had a normal recovery, and after twenty-four hours was well, and seemed to feel well for six days, then developed signs of mania, refusing any food. It was killed on the eighth day.

At necropsy, no deformity of the two sides of the chest was noted. The diaphragm was at the same level on both sides (fifth intercostal space). The

65. Ellenberger and Baum: Anatomie des Hundes, Berlin, 1891, p. 325.

right pleural cavity was normal. The right lung was slightly (one sixth) larger (Fig. 11) than the left. The gross appearance was normal. On the left side there were dense adhesions on the mediastinal side in the region of the hilum and in the adjacent two thirds of the upper lobe. Elsewhere, the lung was free. A firmer consistency of the left lung was noticeable, especially in the upper lobe. The whole lung appeared blue red. There was no thickening of the pulmonary pleura. On section, the left lung was firm, with diminished crepitus. The right ventricle was not enlarged. Microscopically, on the left side, the alveoli were mostly filled with blood. There were hyperplasia and desquamation of the epithelial cells, some of which were phago-

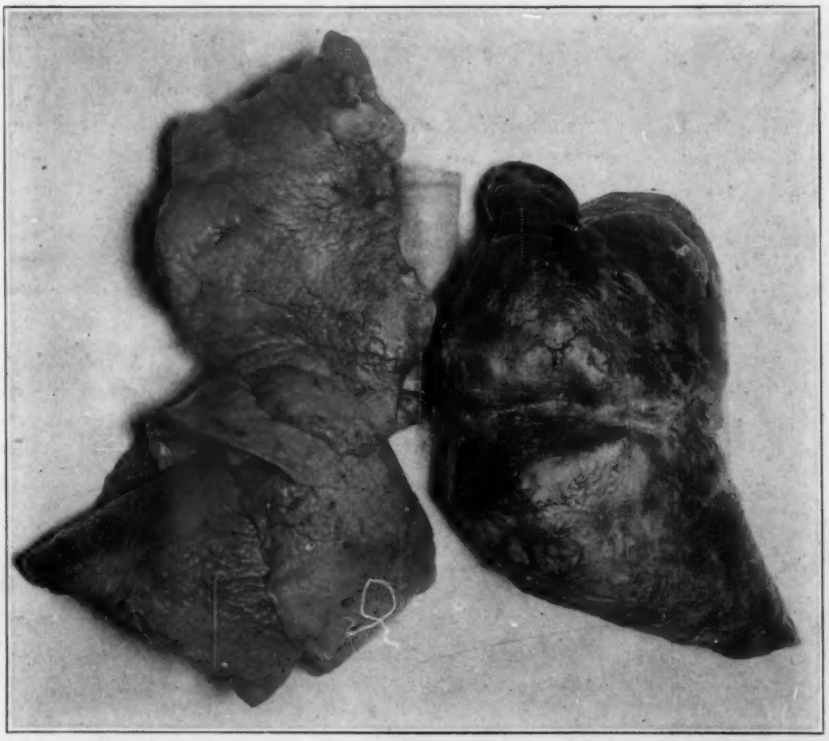

Fig. 11.—Dog lungs eight days after ligation of the left pulmonary artery. The left lung is smaller (one sixth).

cytic. The capillaries were dilated (Figs. 12 and 13). The right side was normal except for scattered areas showing capillary dilatation.

EXPERIMENT 10.—A medium-sized dog, circumference 47 cm., underwent ligation of the left pulmonary artery in the usual way, followed by an uneventful recovery. The animal was lively on the second day.

Roentgenograms taken the day after operation showed a cloudiness of the operated side and no displacement of the heart. The diaphragm made a normal excursion on both sides, thirty-seven days after operation; the heart was in normal position. The diaphragm was contracted on each side in the

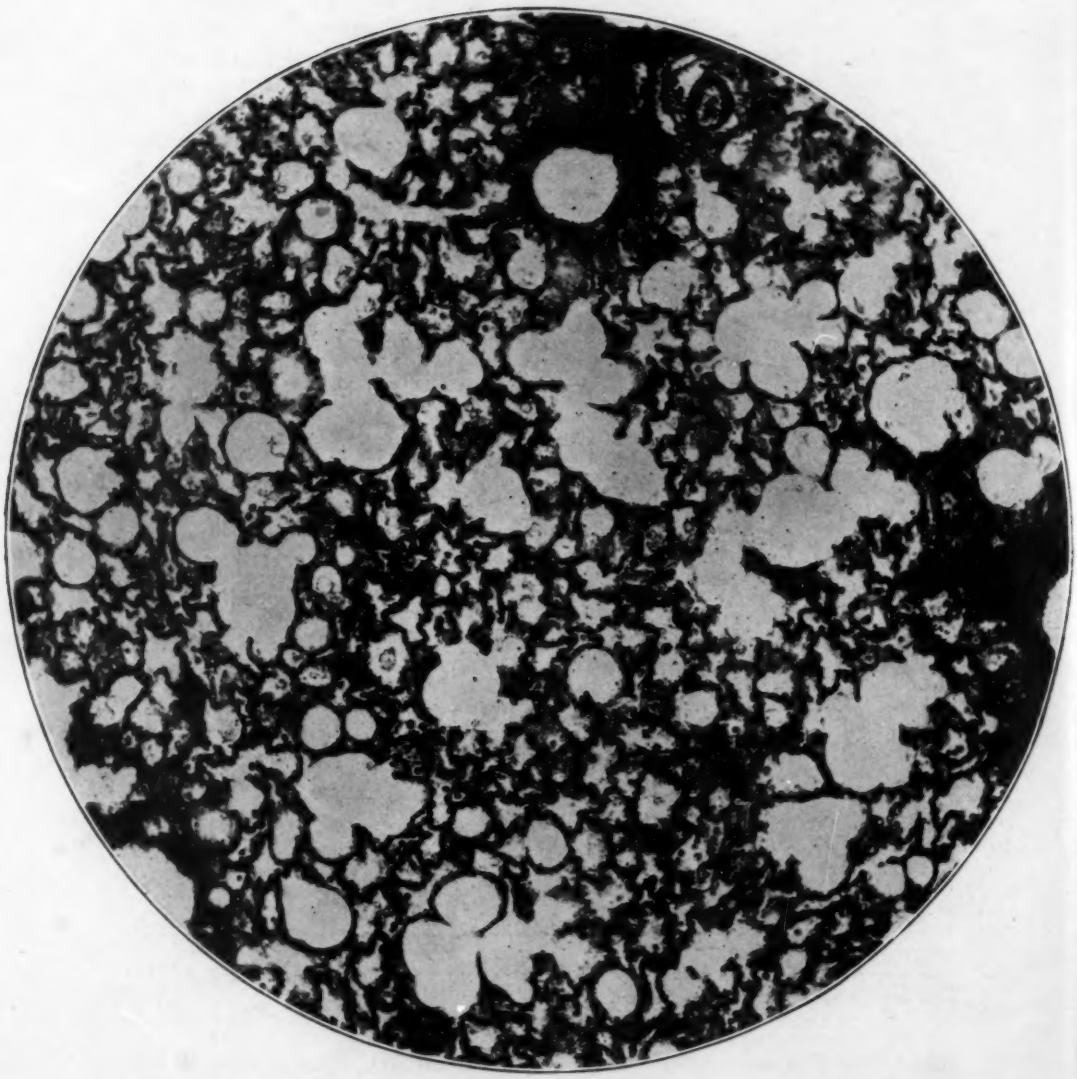

Fig. 12.—Photomicrograph through side of operation (eight days) showing areas in which the alveolar septa show dilated capillaries. The alveolar spaces are free, some containing desquamated alveolar epithelial cells and blood.

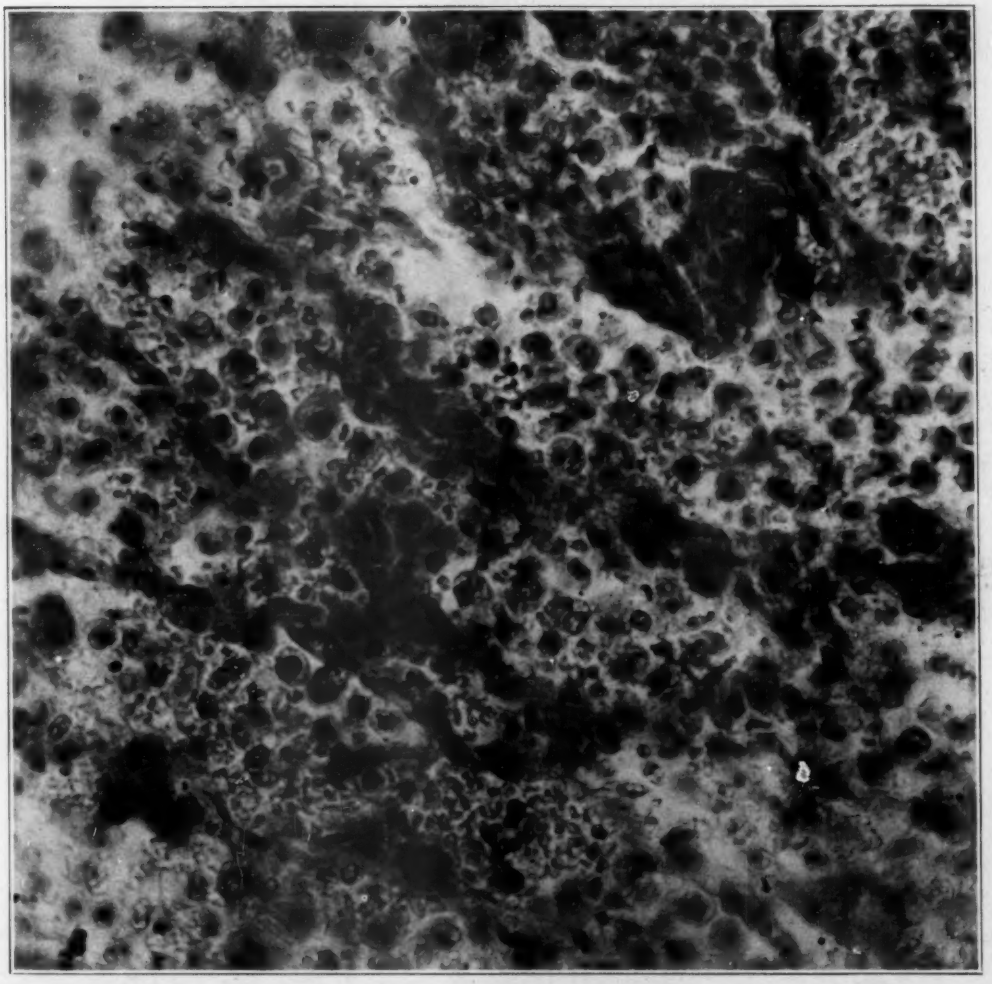

Fig. 13.—High power view of section shown in Figure 12, taken from an area in which the alveolar spaces are filled with blood and desquamated alveolar epithelial cells.

same way. The two lungs appeared clear. Sixty-three days after operation, the condition was the same as after thirty-seven days. The animal was killed sixty-six days after operation.

At necropsy, no deformity of the thorax was noted. The diaphragm on both sides was at the level of the fifth rib. The right lung extended on its medial border far to the left pressing over the anterior mediastinum. The right mediastinal lobe reached to the left lateral chest wall, filling a space between the diaphragm and the left lung. The left lung was densely adherent along the chest wall and the mediastinum. The apex, diaphragmatic and lower

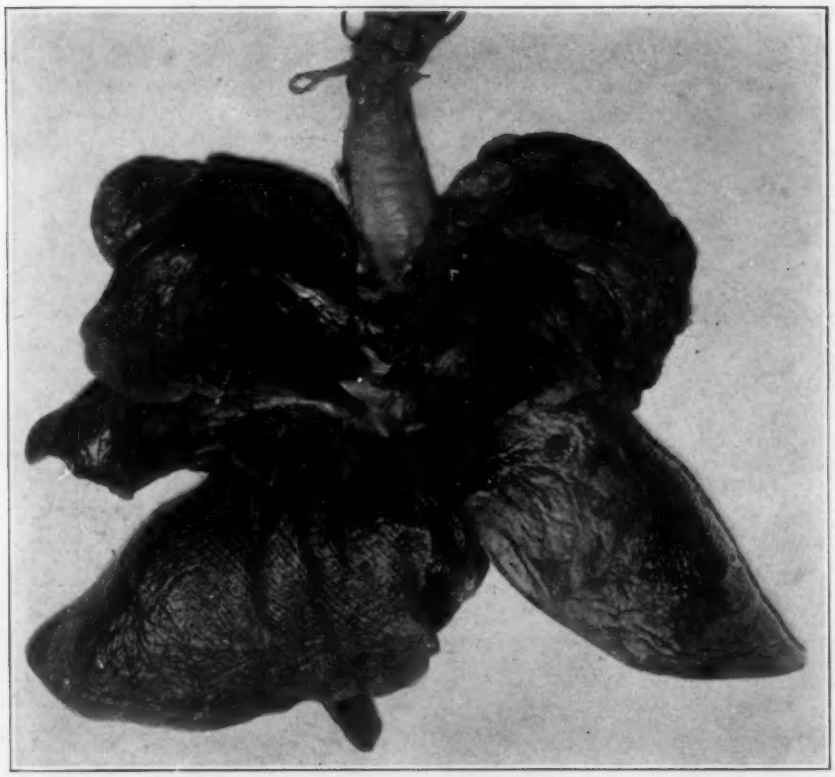

Fig. 14.—Dog lungs sixty-six days after ligation of the pulmonary artery. The slight difference between the two lungs may be noted.

lateral surface were free. The size of the two lungs was about the same (Fig. 14). The consistency was firmer on the left, the air content greatly reduced.

The ligature of the pulmonary artery was embedded in scar tissue. Branches of the pulmonary artery beyond the ligation were not markedly contracted except the one running to the upper lobe. There was no enlargement of the right pulmonary artery.

On the left side, the bronchial artery and its main branches were markedly dilated.

Microscopically, on the left, all the capillaries were markedly dilated, and the alveolar lining cells were proliferating and partly desquamated. The adventitia of the blood vessels thickened. The alveolar spaces were free. The septums were more prominent. The elastic tissue (Weigert stain) had increased. The same picture was found in all the lobes. On the right side, there was dilatation of all the capillaries without any signs of proliferation of the alveolar lining cells. There was no proliferation of the perivascular tissue.

EXPERIMENT 11.—A medium-sized dog, circumference 45 cm., whose left pulmonary artery was ligated, made an uneventful recovery within twenty-four hours. Measurements of the chest in various periods revealed no changes

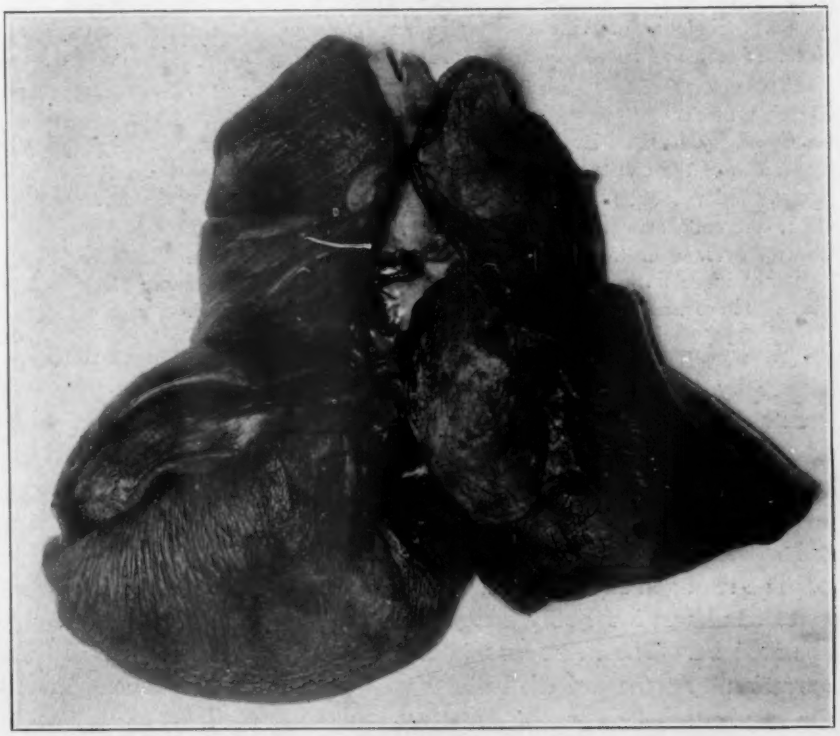

Fig. 15.—Dog lungs 120 days after ligation of the pulmonary artery. The difference between the two sides is very small.

in the two sides. The animal was active up to the time of death, 120 days after operation.

Roentgenograms taken at thirty-eight, sixty-nine and 108 days revealed a gradually increasing displacement of the heart to the left side, first visible after thirty-eight days, more clearly seen after four months. The left upper lobe was rather cloudy (induration). There was no deviation of the vertebral column.

At necropsy, the right lung was normal in appearance. On gross section, it was about one-fourth to one-fifth larger than the left side, and this after postmortem contraction (Fig. 15). The mediastinum was pushed to the left,

and the mediastinal lobe was interposed between the left lung and the diaphragm. The left lung was bluish red and was adherent to the chest wall at the hilum. The consistency was firmer.

The left pulmonary artery and its branches beyond the point of ligature were contracted but not thrombosed, and the wall was intact. The right artery was not enlarged. The bronchial artery on the side of ligation was more than double the size of the right, extending into its branches.

Microscopically, on the left, there was marked dilatation of all the capillaries. The alveolar epithelial cells were conspicuous. Spindle cells were particularly numerous along the blood vessels and the bronchi, and were the dominant type extending in strands for a short distance into the alveolar septums. The elastic tissue was markedly increased (Fig. 16).

On the right side, the capillaries were dilated. The alveolar space was free. There was no fibrous tissue proliferation (Fig. 17).

EXPERIMENT 12.—A medium-sized dog, circumference 52 cm., underwent ligation of the left pulmonary artery, with quick recovery. The animal was always very lively. Even after five months, there was no difference in the two sides of the chest. The animal was sent to the country, where it died, and was buried without notification.

Roentgenograms taken at twenty, sixty, ninety and 152 days, revealed shortly after operation a slowly increasing displacement of the heart to the left, not more noticeable later. The diaphragm was at the same level on both sides. There was no particular cloudiness on the ligated side.

Summing up the findings after ligation of the pulmonary artery, a deformity of the chest was not present, even after four and one half months. In the roentgen-ray examinations, no enlargement of the intercostal spaces was noticed. For two months, the approximation of the two ribs neighboring the incision caused a slight deformity by enlarging temporarily the adjacent spaces. Inspection of the vertebral column did not allow any definite statement concerning a scoliosis.

The roentgen rays immediately after operation and in the first week revealed almost invariably a cloudiness over the upper lobe of the side operated on. The heart was in its normal position shortly after the operation. At the end of the first week, a slight displacement toward the side operated on was noticeable. Beginning with the second week, this displacement became more and more marked. At the same time, the haziness of the lung on the side operated on diminished. A light area above the left diaphragm marked the expansion of the right mediastinal lobe toward the ligated side between the compressed left lung and the diaphragm. The displacement of the heart was most marked during the first month; later this change gradually increased. The diaphragm stayed at the same level through the whole series.

At necropsy, the diaphragm was found at the same level on both sides. The expansion of the intact lung was demonstrated by two facts: 1. The hollowing out of the anterior mediastinum toward the side operated on in its upper and lower part. With each month the grooves

became deeper. In the specimen obtained twenty-four hours after operation, a beginning of this phenomenon could be seen. A few days after the operation, the medial borders of the intact lung crossed the midline for 1 cm., reaching gradually to 3 cm. after four months. These

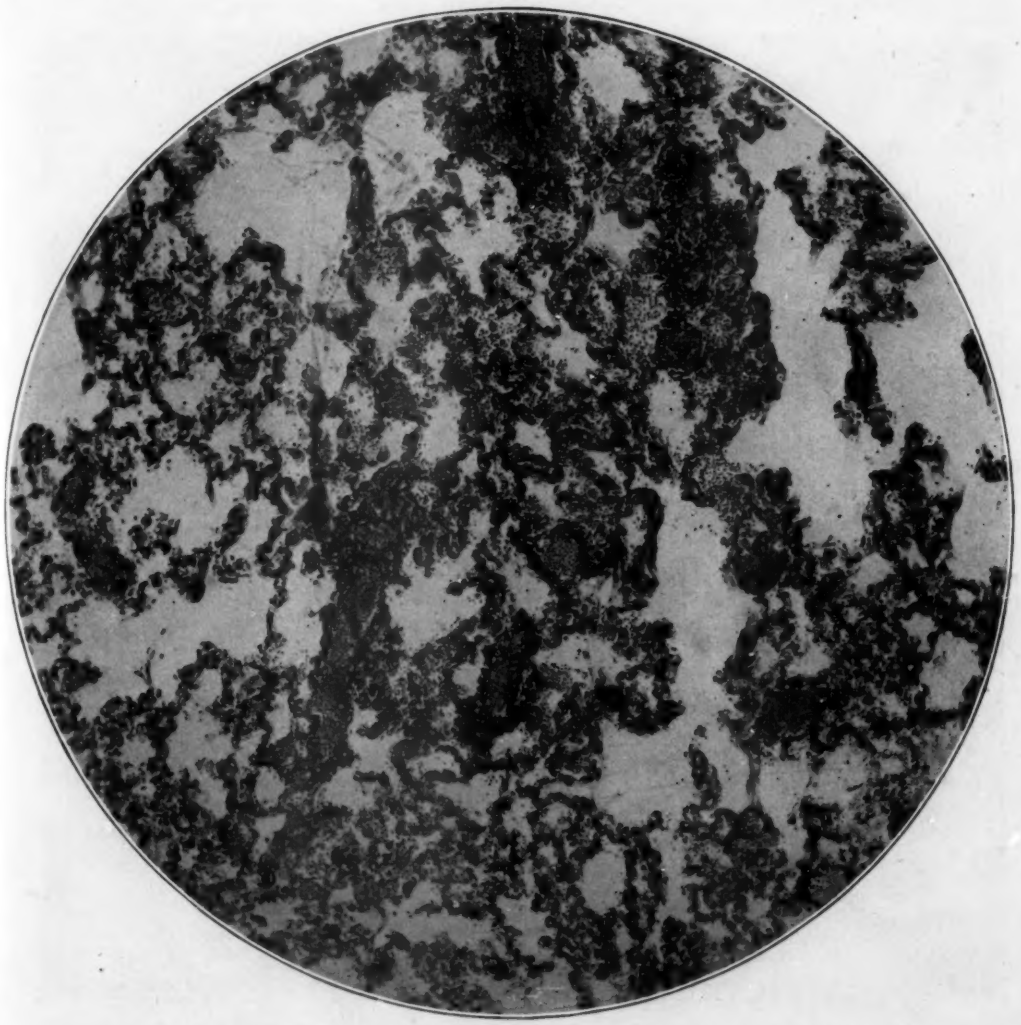

Fig. 16.—Photomicrograph of side of operation 120 days after ligation. There is spindle cell proliferation along the blood vessels and the bronchioli. No trabeculation is present.

physiologically weak spots in the mediastinum are constant in dogs and rabbits. The greatest degree of expansion of the intact lung occurred within the first month. Within this time, an adaptation to the increased

functional demand resulted and became more or less stabilized. The pleural cavities were without fluid, with a glistening pleural covering on the pulmonary and thoracic side. On the side operated on, adhesions were found restricted to two well defined places: (1) in the neighborhood of the ligature along the mediastinal side as a result of

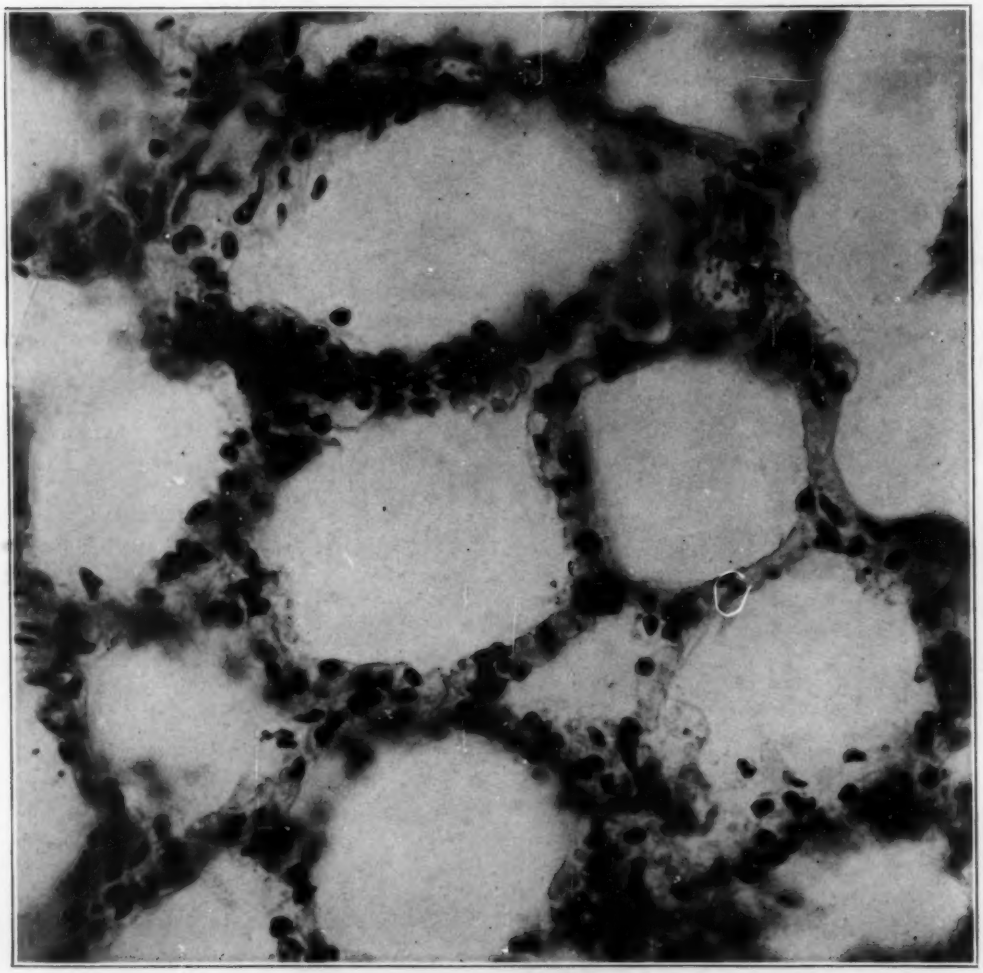

Fig. 17.—Photomicrograph of intact side, 120 days after ligation. The capillaries are dilated within the alveolar spaces. There is an absence of any connective tissue proliferation.

traumatism at the time of operation, and (2) along the wound of incision on the chest wall. The second localization was present in this series only in one specimen, 120 days after operation. This fact might receive further consideration in the next series, in which the diaphragm was

immobilized by resection of the phrenic nerve. The pulmonary pleura showed a noticeable thickening only at the places of adhesion.

The size of the two lungs was partly modified by the partial collapse of the intact side, although the bronchial tree was partly fixed with formaldehyd poured in at the time the dog was killed, and by clamping off the trachea before opening the chest. The distended intact side almost always retracted somewhat, the ligated side being unchanged. As this factor was the same throughout the whole series, it can be taken as a relative measure for comparison of the two lungs. From the beginning, the intact side was found to be larger; but the difference of the two sides became more and more pronounced. The light red hue of the intact side contrasted remarkably with the blue-red coloration on the ligated side. At the same time, the side operated on showed a greater density of tissue. In this series, the difference in the two sides of the lungs was not more than one fourth to one fifth after four and one half months. The air content of the two lungs varied inversely with the consistency, the intact side being normally crepitant, the side operated on distinctly less so.

In studying the size of the two pulmonary arteries (left and right), the lumen distal to the ligature was in no instance thrombosed and the intima was smooth. After sixty-six days, a slight contraction of the vessel distal to the ligature was visible. The heavy white silk ligature was in all cases embedded in firm scar tissue. At 120 days, the diminution in size distal to the ligature was more pronounced, and extended to all the branches. The stump of the ligated artery had the same caliber as the corresponding vessel of the intact side.

The bronchial artery and its main branches on the side of ligation showed a considerable dilatation, first noticeable after sixty-six days. At 120 days, the calibre of the artery on the ligated side was more than double that of the nonligated side.

Microscopically, on the left, there was marked dilatation of all the smaller blood vessels and capillaries. An edema with extravasation of blood made the picture at the end of the first week similar to that in a hemorrhagic infarct. Proliferation and desquamation of alveolar epithelial cells was the response to this extreme stasis. In some areas, dilatation of the capillaries was sufficiently marked to obliterate almost completely the alveolar spaces. They contained in part blood pigment (heart failure cells). They were especially frequent at the beginning of the second week. After three weeks, the alveoli became clear again, the dilated capillaries becoming very conspicuous, as tortuous engorged vessels in the alveolar septums. Besides the cubical alveolar lining cells, spindle cells appeared, arising from the proliferating perivascular tissue. This is the beginning of the fibrosis, developing particularly along the

smaller blood vessels and within the bronchial walls, but not so conspicuous along the larger bronchi as the point of lesser stasis owing to the unchanged bronchial arterial circulation.

After from two to three months, the spindle cells in the alveolar septums increased considerably in number, but the alveolar epithelial cells were in some areas predominant even after 120 days. Strands of cellular connective tissue surrounding the smaller blood vessels and bronchi made their appearance, thus dividing the alveoli into lobules and producing a kind of trabeculation. This, the first stage of fibrosis, which was present at the beginning, four months after simple ligation, will be further observed in a second and larger series now under observation. The microscopic changes were about the same in the different lobes of the ligated side. After two months, the elastic fibers in the perivascular and peribronchial tissue increased. At three months, this process was more pronounced, and at four and one-half months further increased. On the intact side, dilatation of the whole capillary system was striking, being more marked after one and three months than at the beginning. No signs of increased connective tissue formation could be demonstrated even after four months, in contrast to the ligated side.

In ligation of the left pulmonary artery combined with resection (crushing) of the phrenic, the technic was the same as outlined previously. The animals of this series were decimated by an epidemic of distemper. Only nine dogs could be used for our studies. Five died, two, seven, thirteen, twenty and twenty-two days after the operation, with double bronchopneumonia. One dog, the only one in the two ligation series, died one hour after the operation. The ligation caused an immediate irregularity and weakness of heart action. Necropsy revealed a huge, dilated heart (right side).

EXPERIMENT 13.—A medium-sized dog underwent ligation of the left pulmonary artery and resection of the left phrenic nerve. When the chest wall wound was closed, the dog stopped breathing for a moment. Gradually, respiration became more regular; but some hours later, the animal still showed a marked dyspnea, which persisted until death, twenty-four hours after operation.

At necropsy, the diaphragm was 1 cm. higher on the left side. The right lung was expanded, its medial border towards the left, thus forming two hollows in the anterior mediastinum, one above and one below, anterior to the heart. Also the mediastinal lobe showed some enlargement to the left. The right lung was everywhere normal in air content. The lung on the left side was free from adhesions. A few drops of bloody fluid were present in the pleural cavity. The left lung was about the same size as the right (Fig. 18), but of firmer consistency, owing to a marked edema. On section the air content was diminished.

Microscopically, in the left lung, there was marked dilatation of all the smaller blood vessels of the capillaries, less pronounced in the upper lobe. The alveoli were partly filled with clear fluid, and some desquamated

epithelial cells. The alveolar lining cells had proliferated. On the right side, dilatation of the smaller blood vessels was conspicuous. The alveoli were clear.

EXPERIMENT 14.—A small dog underwent ligation of the left pulmonary artery and resection of the left phrenic nerve, with uneventful recovery. The animal was killed one day after operation.

At necropsy, the diaphragm was at the same level on both sides. The right lung extended toward the left. The mediastinal lobe occupied the space between the left diaphragm and lung. The right lung was of normal consistency and air content. The left lung showed some adhesions near the hilum. Otherwise, the pleural cavity was free and the pleura glistening. The left lung was about one

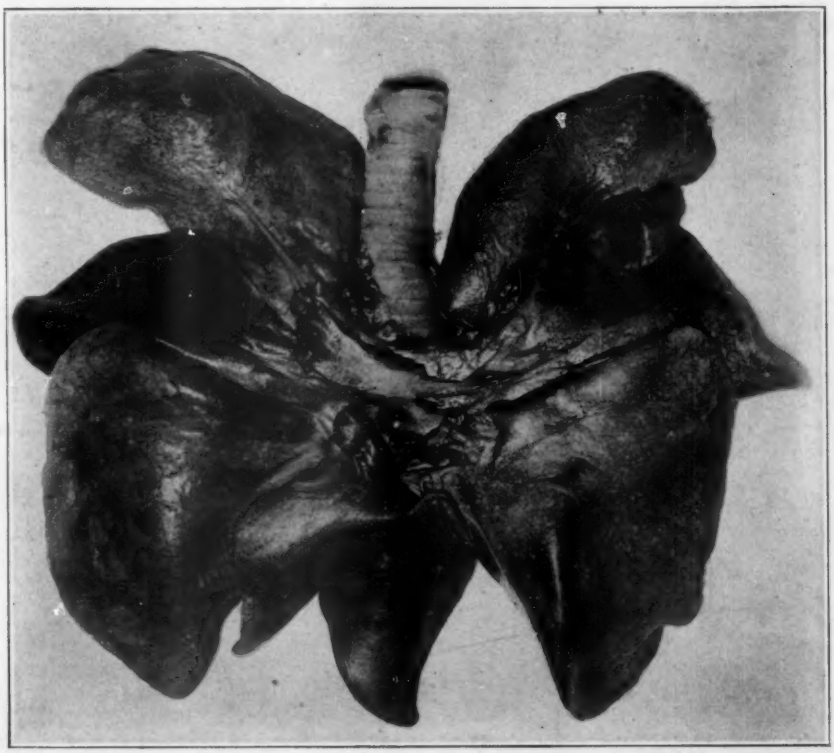

Fig. 18.—Lungs twenty-four hours after ligation of the left pulmonary artery combined with resection of the phrenic nerve. The two lungs are about the same size.

fourth smaller than the right and firmer in consistency. On section, frothy fluid could be scraped away.

Microscopically, on the left, there was great dilatation of all the smaller blood vessels, especially in the lower lobe, with marked proliferation of the alveolar epithelial cells. In the upper lobe, the capillaries were tortuous and engorged. Proliferation of the epithelial cells was the same as in the lower lobe, causing a thickening of the alveolar septums.

On the intact side, there was general dilatation of all the capillaries and smaller blood vessels, without any signs of proliferation of the epithelial cells.

EXPERIMENT 15.—A medium-sized dog was subjected to ligation of the left pulmonary artery and resection of the phrenic nerve. Immediately afterward, there was irregularity of the heart action, but no noticeable change in the rate of respiration. Recovery was gradual. The dog remained rather droopy up to the eighth day, when he was killed.

At necropsy, no deformity in the configuration of the two sides of the chest was found. The diaphragm was at the same level on both sides. The medial portion of the right lung was displaced to the left, forming the usual hollows in

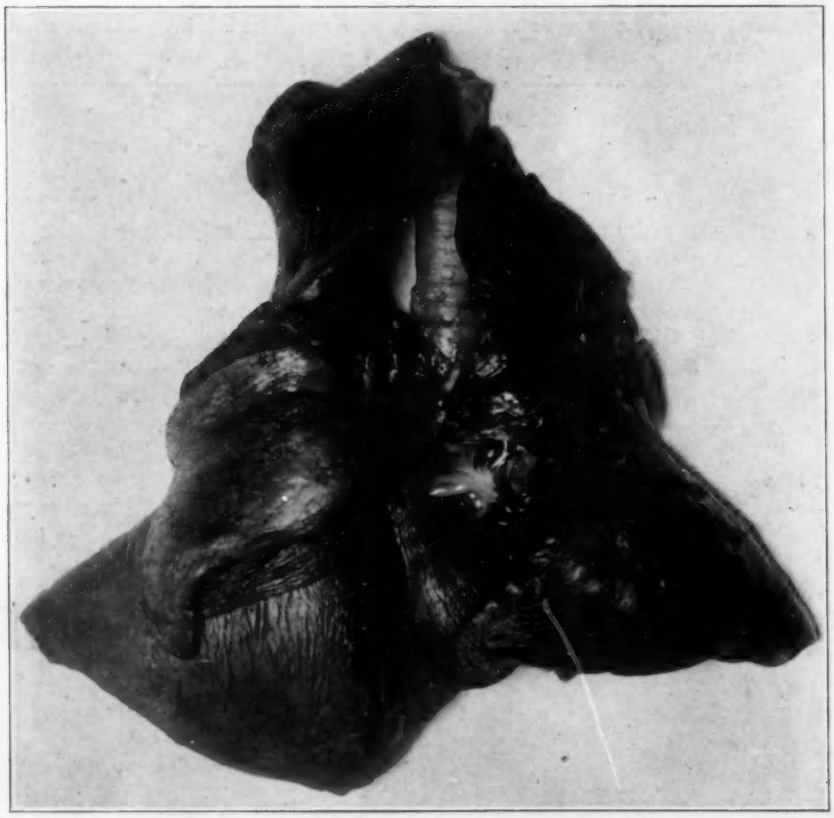

Fig. 19.—Dog lungs eight days after ligation of the left pulmonary artery combined with resection of the phrenic nerve. The marked difference in size between two lungs may be noted.

the anterior mediastinum, 2 cm. from the midline and more pronounced than in the preceding specimen. The mediastinal lobe extended to the left. The heart showed considerable twisting along its basis to the left. In the left pleural cavity, there was about 20 c.c. of bloody fluid and marked injection of the pleural sheaths. Adhesions along the scar of operation and in the hilum region, close to the ligatures, were noted. The left lung was about one-third smaller than the right (Fig. 19) and was bluish red, and firm in consistency. The cut surface was moist, and there was almost no frothy fluid.

Microscopically, dilatation of all the capillaries impinging on the alveolar spaces was seen. In some areas, the alveoli were filled with blood. In a small irregularly outlined area where the alveoli were filled with blood, the nuclei did not take the stain. There was proliferation of the alveolar lining cells. The spindle cells of the perivascular tissue were increased (histiocytes), and there was present some round cell infiltration. The picture throughout the

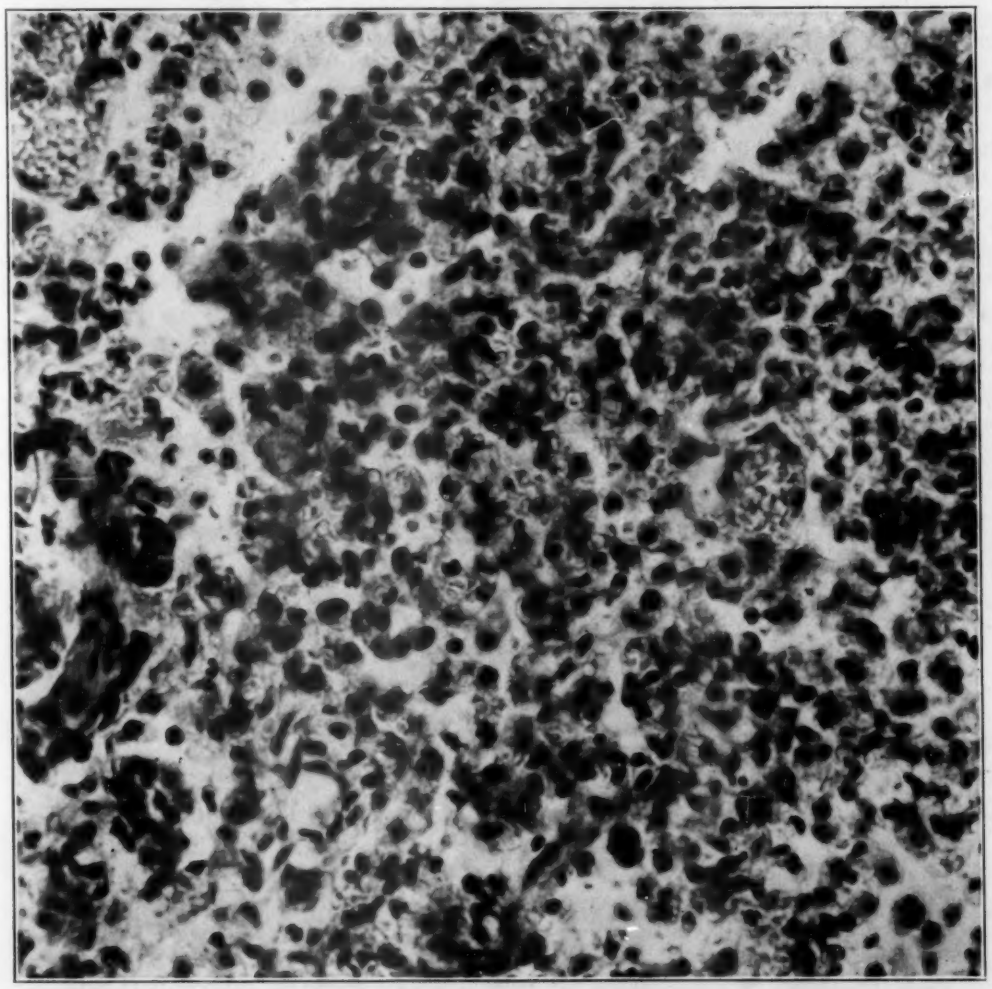

Fig. 20.—Photomicrograph of the side of operation (eight days after ligation and phrenicotomy). There is marked dilatation of all the capillaries partly filling the alveolar spaces. The alveoli are partly filled with blood mixed with desquamated alveolar epithelial cells.

lung was uniform. Macrophages were also found in the alveolar spaces (Fig. 20).

On the intact side, the dilated capillaries were the only remarkable feature.

EXPERIMENT 16.—A large dog, subjected to ligation of the left pulmonary artery and resection of the phrenic nerve, made an uneventful recovery without signs of dyspnea or disturbances of the heart rate. It was killed after fourteen days.

At necropsy, the diaphragm was at the same level on both sides (contracted stage at death). On the left side, the diaphragm was rather flabby, but no thinning or change in color was observed. The right lung was pushed over to the left for 2 cm. at the physiologically weak places in the mediastinum. The right mediastinal lobe was expanded toward the left. Normal consistency and air content were noted. The left lung was adherent on the mediastinal side; the other surfaces were free. The lung was bluish red; one third smaller than the right; much firmer in consistency; the cut surface moist, with frothy fluid. On the right side, there was uniform dilatation of all blood vessels as far as to the capillaries. There was no cell proliferation in the alveolar septums.

Microscopically, on the left side, compact strands of young connective tissue crossed the field, dividing the uniform alveolar structure into lobules. In some places, there were dilated capillaries, and marked proliferation of the alveolar epithelial cells and of spindle cells arising from the perivascular tissue with some round cell infiltration. In some areas the alveoli encroached on the enlarged capillaries; in other places, the lumina of the alveolar spaces were empty. In the upper lobe, no strands of fibrous tissue were found. Scattered through the alveoli were phagocytic macrophages with blood pigment, sometimes in clusters.

EXPERIMENT 17.—A fat dog, subjected to ligation of the left pulmonary artery and resection of the phrenic nerve, made an uneventful recovery. During the first twenty-four hours, the animal was rather droopy. Later, there were no signs of discomfort of any kind. The animal was killed twenty-three days after operation.

Roentgen rays, three days after operation, revealed a marked elevation of the diaphragm on the paralyzed side. The mediastinum was pushed to the side operated on, the mediastinal lobe occupying the space between the left diaphragm and the left lung.

At necropsy, the diaphragm was at the same level on both sides. The left side of the diaphragm was lighter than the intact side, which had a dark hue. The left diaphragm was thinner, with a sharp border line in the midline, anteriorly as well as posteriorly.

The right lung, especially the mediastinal lobe, expanded to the left for 3 cm., by emphysematous dilatation. The right lung was pinkish. The air content was increased.

The left lung was adherent to the chest wall along the scar of incision and toward the mediastinum. There was no thickening of the pulmonary pleura. The lung was bluish red, one third smaller than the right (Fig. 21); of uniformly firm consistency throughout, and subcrepitant. There was no enlargement of the bronchial artery on the operated side.

Microscopically, on the left, there were bands of very vascular fibrous tissue with spindle cells crossing the field, intermingled with thickened alveolar septums due to the proliferation of spindle cells of the perivascular tissue. In some areas, the cubical alveolar epithelial cells were almost completely replaced by spindle cells. Phagocytic macrophages with blood pigment and round cells were scattered in these strands, but were also free in the alveoli. In some places, especially in the upper lobe, extremely dilated capillaries completely

filled the alveoli. Spindle cells were predominant. In other areas, cubical epithelial cells were quite numerous. The process was less advanced in the upper lobe and along the large bronchi. Along the pleural adhesions on the mediastinal side, dilated capillaries were the predominant feature. In the right lung, there was marked dilatation of all the smaller vessels and capillaries. No cell proliferation was manifest.

EXPERIMENT 18.—A medium-sized dog, circumference, 49 cm., whose left pulmonary artery was ligated and phrenic nerve thoroughly crushed for a distance of 2 cm., suffered no alteration of the respiration or heart action.

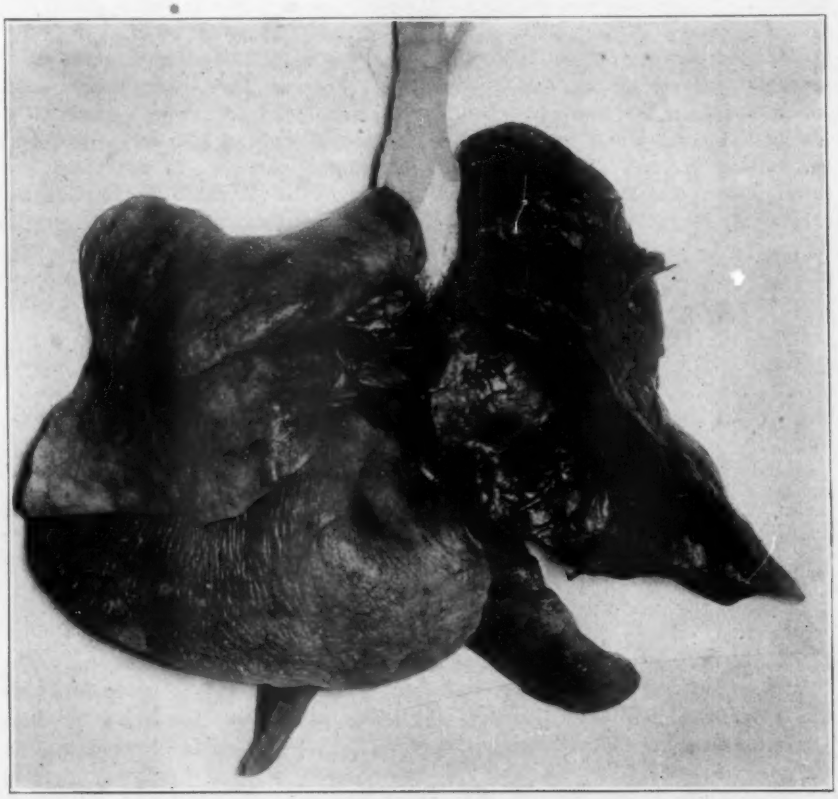

Fig. 21.—Lungs twenty-three days after ligation of the left pulmonary artery combined with resection of the phrenic nerve. The gradual decrease in size of the side of operation may be noted in this series.

Recovery was uneventful. The animal remained well up to the day of death. It was killed by ether-formaldehyd, sixty days after operation.

Roentgenograms taken after fourteen and fifty days revealed marked displacement of the mediastinum and heart to the left, and elevation of the diaphragm on the side operated on.

At necropsy, there was no deformity of the two sides of the chest. The diaphragm was 1.5 cm. higher on the left. The light color of the left side contrasted with the dark hue of the right. In the thinned left side of the

diaphragm were red muscle strands mixed with light brownish ones. There was a sharp borderline of differentiation between the two diaphragmatic sides in the midline.

The medial portion of the right lung pushed the mediastinum to the left for 3 cm. The mediastinal lobe extended far over to the left.

There were some adhesions of the left lung on its mediastinal side. Otherwise the pulmonary pleura was free. The lung was one-third smaller than the right and much firmer in consistency. Throughout the upper and lower lobe, the lung was uniformily subcrepitant.

The pulmonary artery was not particularly narrowed beyond the point of ligature. There was no enlargement of the artery on the right side. The bronchial artery on the ligated side was not markedly enlarged.

Microscopically, on the left, there were strands of vascular fibrous tissue crossing the section in various directions, dividing the alveolar fields into lobules. In the intervening alveolar septums, spindle cells were predominant. Cubical alveolar lining cells partly disappeared, only deeply stained spindle cells being present. The capillaries were hugely dilated. In the upper and lower lobes, the same changes were noted. With Weigert's stain, marked thickening and proliferation of the elastic fibers, particularly within the strands of connective tissue of the lower lobe, were seen. The right lung showed no cell proliferation in the alveolar septums. Dilatation of the capillaries was very conspicuous throughout the specimen.

Experiment 19.—A medium-sized dog, subjected to ligation of the left pulmonary artery and resection of the phrenic nerve, after the operation was rather inactive for two days. Later, the animal became normal and was very lively up to the time it was killed by ether anesthesia and formaldehyd ninety-three days after operation.

Roentgenograms taken seven, forty and seventy days after operation revealed a slight displacement of the mediastinum and heart to the left, slightly more pronounced after seventy days. The diaphragm was much higher and more nearly dome shaped on the left side. The area of the left lung was darkened, owing to increased density of the tissue. A light area in the lower part formed by the right mediastinal lobe was pushed over toward the side operated on.

At necropsy, there were no variations in the chest circumferences. The diaphragm was at the same level on both sides. The color on the left side was a uniform light brown, with a sharp line of demarcation in the midline. The intermuscular spaces were enlarged. The left part of the lumbar portion was much thinned. The left lung showed adhesions along the scar of operation and in the hilic region close to the site of ligation. The lung was one fourth smaller than the right one, bluish red and much firmer in consistency. The air content was reduced.

The right lung extended to the left for 4 cm. in the upper and 3 cm. in the lower part. The mediastinal lobe was also displaced to the left, and interposed between the diaphragm and the left lung. There was a normal air content throughout. The left bronchial artery was from two to three times the size of the right and filled with dark blood. The branches were also enlarged. The walls of the left pulmonary artery distal of the place of ligation was contracted. The stem of the right pulmonary artery and its branches were somewhat enlarged.

Microscopically, in the left lower lobe, there was beginning a strand-like proliferation of connective tissue around the blood vessels. Some of the

alveolar epithelial cells were poorly stained. In some areas, the alveolar septums appeared to be lined by spindle-shaped connective tissue cells. In the upper lobe, there were dilated blood vessels, and perivascular and peribronchial connective tissue hyperplasia was noted. There was no strand formation. The elastic tissue was increased within the alveolar septums and in the peribronchial tissue. There was no thickening of the pulmonary pleura other than in the places of adhesions.

On the intact (right) side, the small blood vessels and capillaries were hugely dilated, without any tendency to connective tissue proliferation around the blood vessels and the bronchi.

EXPERIMENT 20.—A medium-sized dog underwent ligation of the left pulmonary artery. A vein coming from the upper and one draining partly the lower lobe were narrowed by a silver wire to one third of their primary lumen. The phrenic nerve was resected for a distance of 2 cm. For the next two days, the animal was somewhat dyspneic and inactive. Following this, recovery was complete. The animal was killed 136 days after operation.

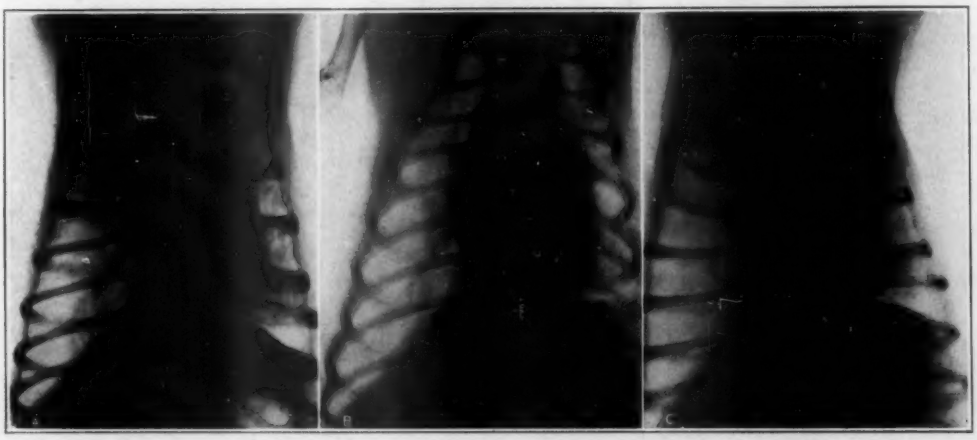

Fig. 22.—Dog chest following ligation of the left pulmonary artery combined with resection of the phrenic nerve. *a*, sixty days after operation; *b*, ninety days after operation; *c*, 130 days after operation. The gradual elevation of the paralyzed diaphragm may be noted. Some displacement of the mediastinum with the heart is noticeable.

Roentgen-ray examination, sixty days after operation (Fig. 22a), revealed marked displacement of the heart to the side operated on. The apex was elevated above its original level. Ninety days after operation (Fig. 22b), displacement to the left was more pronounced. A clear area above the left diaphragm indicated the place occupied by the expanded right mediastinal lobe. The compressed lung was rather cloudy as a result of the increased density.

At necropsy, the diaphragm on the left side was 1.5 cm. higher. There was a sharp difference between the two sides, the left side forming a thin membrane, light brown, with a thinned and shrunkened muscle portion. The central tendon and spaces between the different muscle portions were enlarged. There was a sharp demarcation of the two sides in the midline.

The right lung extended in its medial portion over the midline to the left. The right mediastinal lobe occupied a large area below the left lung and above the diaphragm. There was torsion of the heart to the left and backward, resulting from expansion of the right lung and elevation of the paralyzed diaphragm. The right lung was normally reddish pink, and crepitant. There were extensive, firm adhesions of the left lung along the mediastinal and in the lower posterior and lateral aspect. The remaining pleural surface was free. The pulmonary pleura was not thickened. The left lung was one half

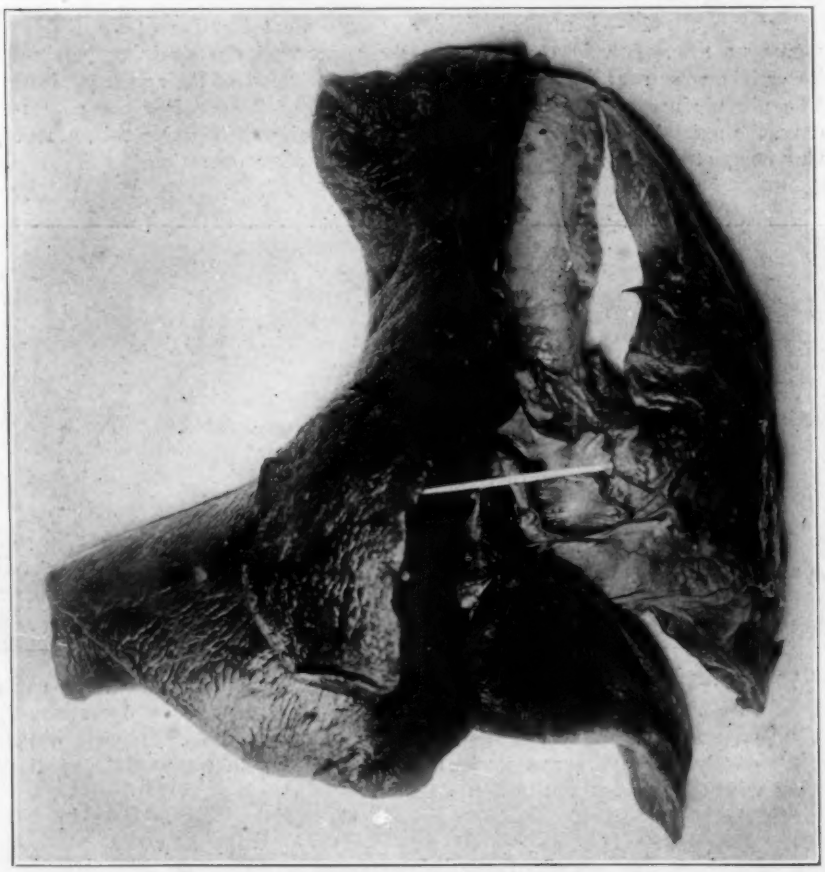

Fig. 23.—Lungs 136 days after ligation of the left pulmonary artery combined with resection of the phrenic nerve. The marked shrinking of the side of ligation may be noted. (Compare with Figure 15, in which ligation alone was performed 120 days before.)

the size (Fig. 23) of the right. The lower half was bluish red, very firm in consistency and of reduced air content. On cross-section the dilated bronchi were visible. The upper lobe was red and moderately subcrepitant. The pulmonary artery and branches beyond the ligature were reduced in caliber. The stem of the nonligated side, together with the larger branches, was

somewhat enlarged. The bronchial artery and its larger ramifications on the ligated side were about double in caliber those of the intact side.

Microscopically, on the left, the perivascular and peribronchial connective tissue was proliferating strands of cellular fibrous tissue crossing the section in various directions dividing the area of uniform alveoli into lobules. This

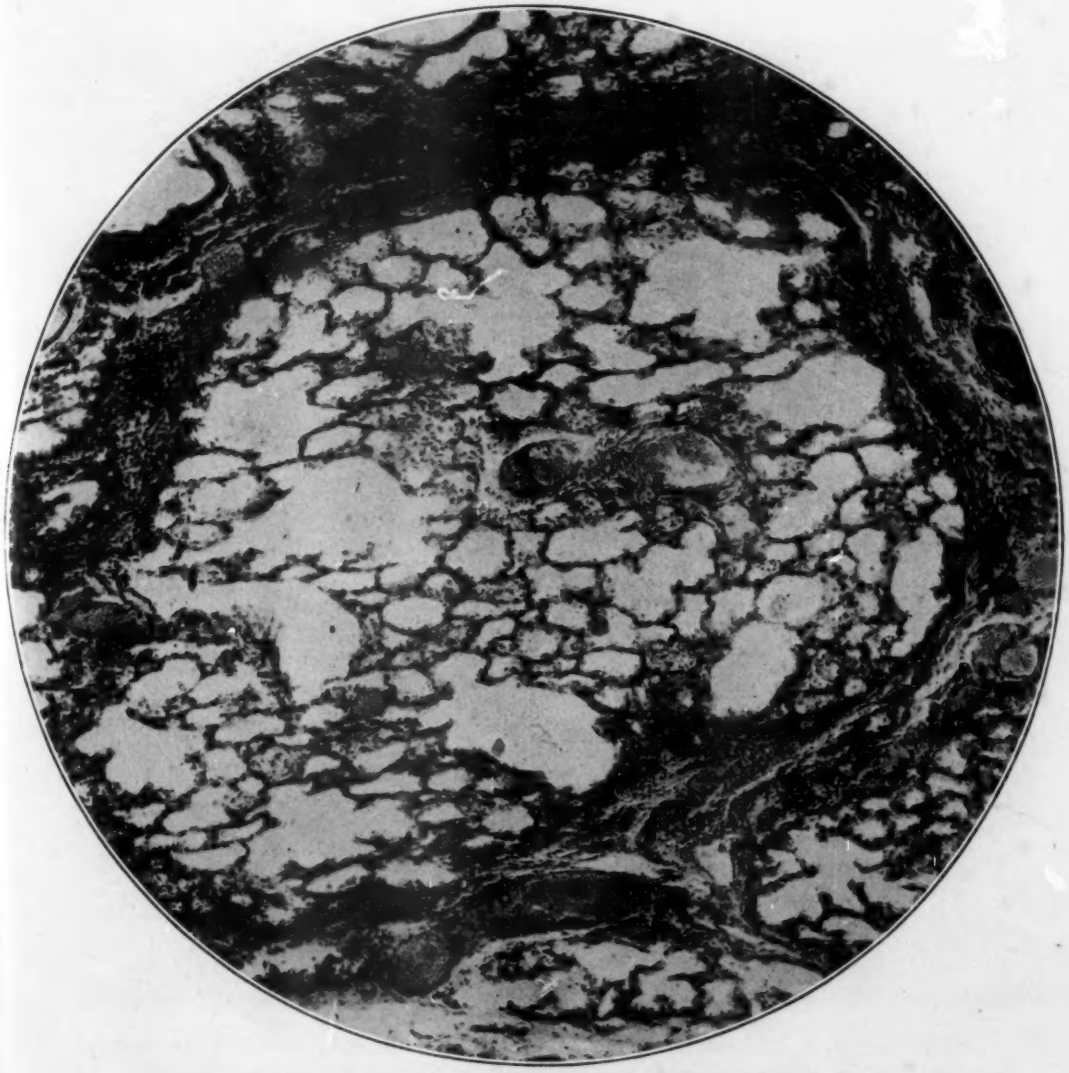

Fig. 24.—Low power photomicrograph of side of operation, 136 days after operation.

trabeculation (Figs. 24 and 25) was more advanced in the lower lobe. In the upper lobe, dilatation of all blood vessels was evident. These lobules enclosed alveolar spaces with dilated smaller blood vessels and capillaries.

The alveolar spaces were free, sometimes containing phagocytic cells. The alveolar epithelial cells were faintly stained. Macrophages were more numerous within the strands of the vascular connective tissue, but also along the remaining alveolar septums, filled with granular blood pigment. There was a marked thickening and proliferation of the elastic tissue (Weigert) noted within these strands. The connective tissue was also increased within the

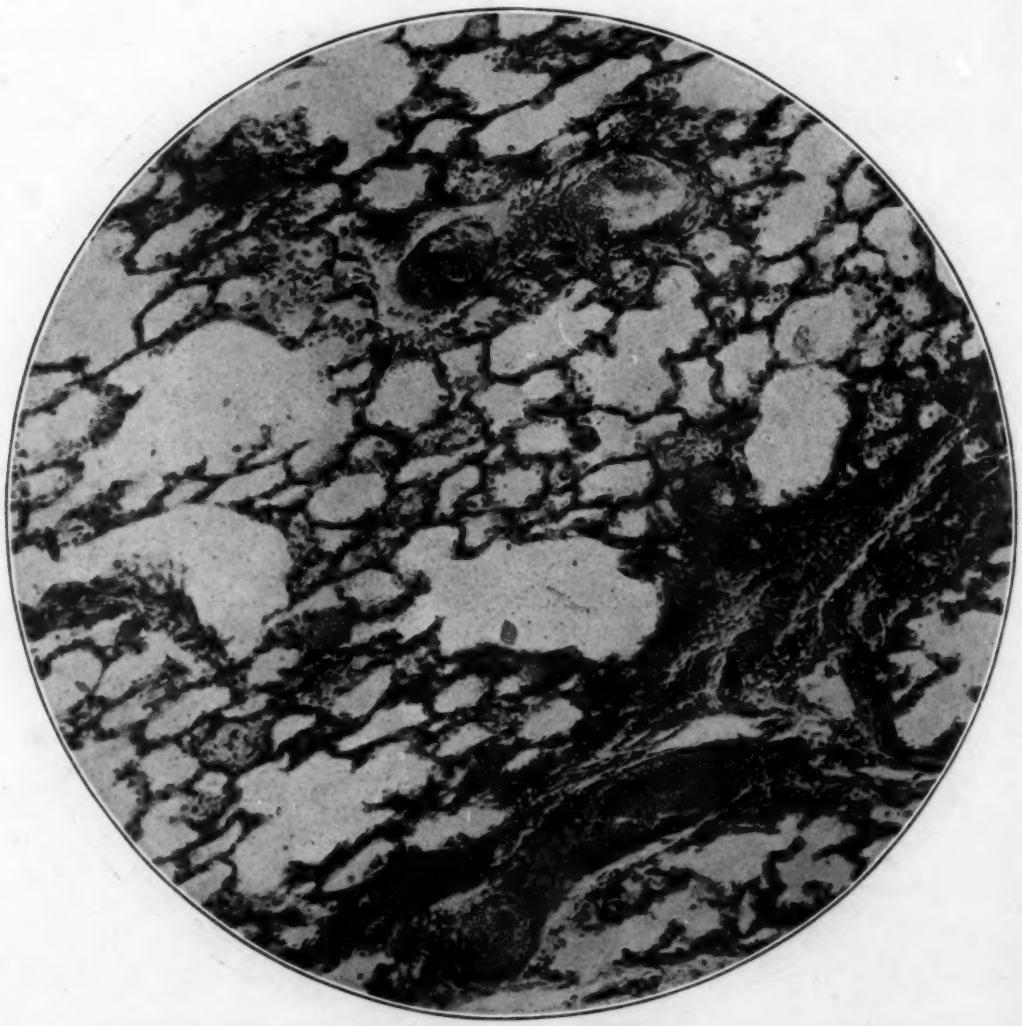

Fig. 25.—High power photomicrograph of section shown in Figure 23. Strands of young connective tissue divide the field in lobules (trabeculation). Within these lobules, alveolar septa with dilated small blood vessels and capillaries are seen. Spindle cells predominate within the septa.

alveolar septums. In some places (Fig. 26), these elastic fibers could be followed, branching off from the strands into the alveolar septums. These elastic fibers were arranged parallel.

On the intact side were hugely dilated smaller blood vessels and capillaries. There was no connective tissue proliferation (Fig. 27).

EXPERIMENT 21.—A medium-sized dog, circumference 41 cm., subjected to ligation of the left pulmonary artery, and crushing of the phrenic nerve for a length of 2 cm., made a normal recovery. The day after the operation, the dog was quite active. It was killed 140 days after operation.

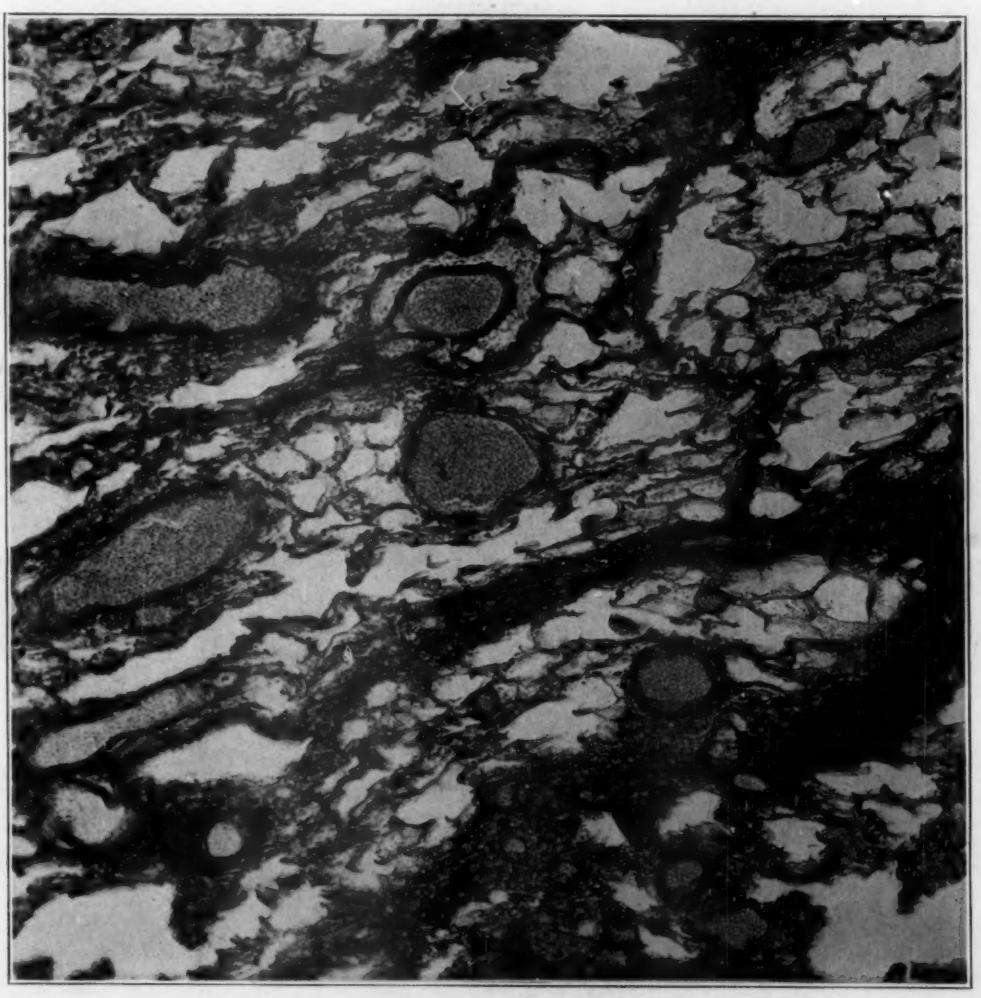

Fig. 26.—Photomicrograph of the side of operation after 136 days (Weigert's elastic stain). Increase of elastic tissue goes parallel with connective tissue proliferation.

Roentgenograms taken after sixty and after ninety-one days revealed flattening of the paralyzed diaphragm. After 130 days, a marked change was noticeable, pointing to a return of motor function on the crushed side. The left diaphragm was dome shaped again. The heart was pushed to the side operated on after sixty days, not changing later.

At necropsy, the diaphragm was on the same level on both sides. The left half was of light brownish tint, contrasting with the red hue of the right side. Atrophy was considerably less, as in the specimen of a dog 136 days after resection of the phrenic.

The right lung was displaced to the left for 3 cm. The mediastinal right lobe also was expanded far over to the left, and was interposed between the

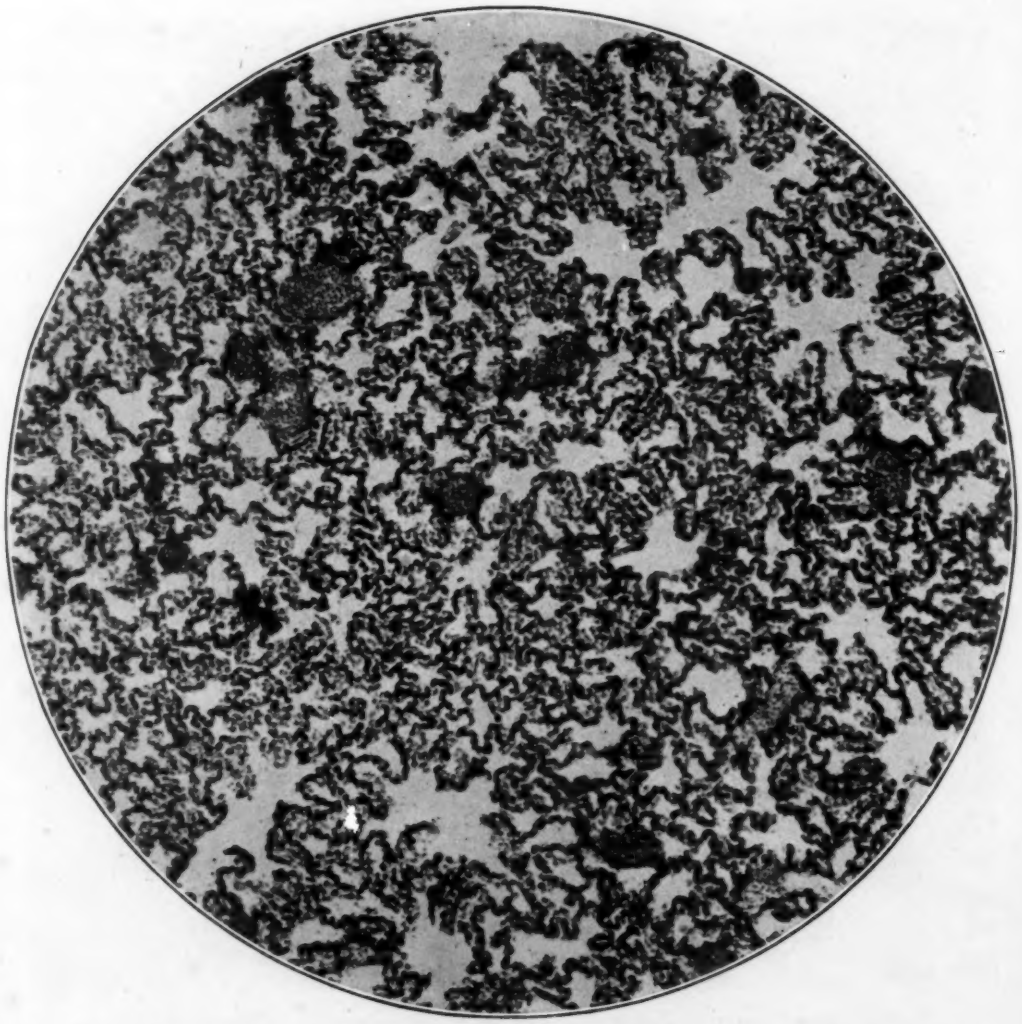

Fig. 27.—Photomicrograph of the intact side, 136 days after operation. The dilated capillaries and small blood vessels are conspicuous. There is no connective tissue proliferation.

left diaphragm and lung. The rest of the right lung showed normal consistency and air content.

The left lung was adherent to the anterior chest wall along the scar of operation. There were also some adhesions in the region of the ligation. The

remainder of the pleural covering was free, with normally glistening pleura. Distal to the ligature, the pulmonary artery was narrowed. There was slight enlargement of the nonligated right pulmonary artery, extending into the larger branches. The two bronchial arteries originated from a common stem on the posterior right aspect of the descending aorta at the level of the fourth

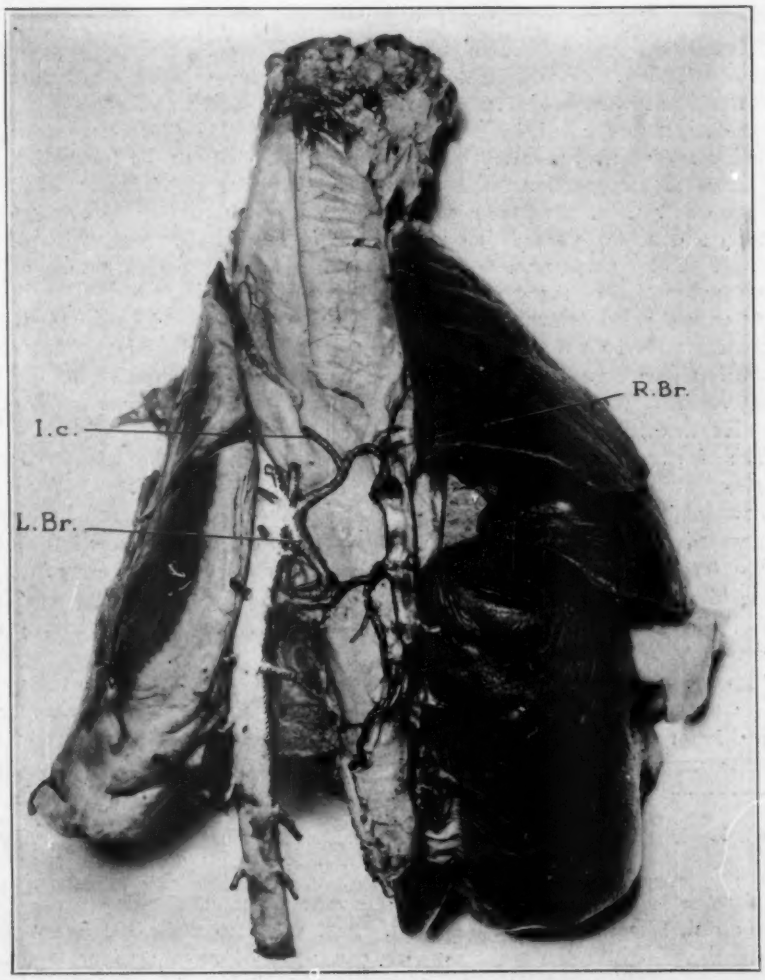

Fig. 28.—Lungs 140 days after ligation of the left pulmonary artery combined with crushing of the phrenic nerve (posterior aspect). The different size of the two lungs may be noted. The left bronchial artery, *L. Br.*, has more than twice the caliber of the right, *R. Br.* An intercostal artery, *I. c.*, is branching off from the right bronchial artery.

intercostal artery. After a short distance, the right and left bronchial arteries branched off. The left bronchial artery was twice the size of the right (Fig. 28). The consistency of the whole left lung was firm; the air content was reduced.

Microscopically, in the left lung, the alveoli were outlined by hugely dilated capillaries surrounded by proliferating connective tissue, containing some faintly staining alveolar lining cells with and without dark granular blood pigment. There were strands of vascular connective tissue with parallel arrangement of the spindle cells. Phagocytic cells were scattered throughout. The elastic tissue (Weigert) was increased. In the right lung, there was dilatation of all the smaller blood vessels and capillaries, without any signs of proliferation of connective tissue.

EXPERIMENT 22.—A medium-sized dog, semicircumference 24 cm., whose left pulmonary artery was ligated and phrenic nerve crushed thoroughly for a distance of 2 cm., made an uneventful recovery, and was always lively up to the time it was killed, by ether and formaldehyd, 136 days after operation.

The roentgen rays revealed displacement of the heart to the left, noticeable fifty days after operation. Later, the condition was unchanged. The diaphragm was high on the paralyzed side and rather flat. After eighty days, the position was still the same; but 120 days after operation, the elevation of the left side of the diaphragm was less visible, and there was a return of the motor innervation of the paralyzed muscle.

At necropsy, no deformity of the chest wall was seen. The diaphragm was at the same level on the both sides; the circumference was equal. The color of the left side was light brown; of the right, reddish. Thinning of the left unilateral area was less pronounced than when the phrenic was cut for the same length of time.

The right lung displaced the anterior mediastinum to the left for 3 cm., forming grooves determined by the physiologically weak places. Also the mediastinal lobe was pushed way over to the left. The air content of the right lung was great. It was pink, contrasting with the dark blue of the left side.

The left lung was one third smaller than the right. There were adhesions at the hilum about the site of ligature. The remainder of the lung was free, with a normal pleural covering. The left lung was firmer in consistency and subcrepitant.

Into the abdominal aorta, a bismuth emulsion (Hill)[66] was injected under a pressure of 150 mm. of mercury. The right auricle and ventricle were opened before the injection was started. A distension of both lungs resulted, more marked on the right side as a result of the dilatation of all the capil-

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66. ℞

	Gm. or C.c.	
Bismuth oxychlorid	17	gr. cclv
Gum acacia	10	gr. cl
Water q. s. ad	100	fl 3iiiss

Dissolve 10 gm. of gum acacia in hot water, rub in chemically pure, not commercial, bismuth oxychlorid 17 gm. Add water to make 100 c.c., making an emulsion. Filter the mass through one layer of linen or four layers of cheese cloth. This emulsion may stand for several days, but should be again filtered before using if left to stand for a day or so (personal communication of Dr. Hill, anatomic department of Johns Hopkins University).

Another prescription was published by Gross: Soak 300 gm. of French gelatine for two hours in 1,200 c.c. of cold distilled water. To this, add 1,000 gm. of finely powdered barium sulphate, 500 c.c. of distilled water and 2 gm. of thymol. Heat over water until the gelatine dissolves and stir until the whole mass becomes a homogeneous milky fluid. Filter through two layers of victoria lawn (Gross, Louis: The Blood Supply of the Heart, New York, 1921).

laries, owing to the mechanism demonstrated by von Basch.[67] The expansion of the two lungs was due to the dilatation of the alveolar septums caused by the filling of the capillaries. The detailed findings on the two sides were as follows: On the left side, filling took place through the bronchial artery, which originated from the seventh left intercostal artery and was three times the size of the corresponding vessel on the right. All the branches of this artery and all capillaries of this lung were injected with bismuth. The pulmonary veins did not contain any bismuth in the larger branches up to a point 2 cm. from the left auricle. There the bismuth, mixed with blood, was pressed in from the left auricle. The branches of the bronchial artery accompanying the bronchi were particularly impressive owing to enlargement similar to that of the main stem.

The filling of the right lung took place from the left ventricle, the left auricle and the pulmonary veins. The bronchial artery of the right side arising from the fifth intercostal artery was small. On cross-section, there was not such a uniform picture of dilated vessels filled with the mass on this side as was present on the ligated side. The whitish vessels were rather accompanying the bronchi and their branches, and the capillaries did not stand out as well as on the operated side. Below the pulmonary pleura, there was not the same web of fine white capillaries as on the left side. The tributary capillaries of the bronchial artery were not so much dilated as on the side operated on. The higher pressure in the dilated bronchial artery had reversed the stream on the left side.

There was shrinking of the left pulmonary artery and its larger branches, beyond the point of ligation embedded in scar tissue. The right side of the heart contained no bismuth. The right pulmonary artery and its larger branches, which showed a moderate enlargement of its calibre, were free from bismuth.

Microscopically, the left lung was divided into lobules of alveoli encircled by strands of fibrous tissue. Alveoli, with marked dilatation of all the capillaries, were partly filled with bismuth. Beside the alveolar epithelial cells, spindle cells were seen arising from proliferation of the perivascular connective tissue. Along the large bronchi, the thickening of the peribronchial tissue was not so pronounced as around the dilated small bronchi arterioles and capillaries. Stasis was not so marked, owing to the supply by the bronchial artery and its efferent veins. Alveolar epithelial cells, faintly staining, were partly filled with granular blood pigment.

There were hyperplasia and hypertrophy of the elastic fibers along the smaller blood vessels and the capillaries in the alveolar septums. Thickening was pronounced also within the pleural adhesions.

On the nonligated side, there was marked distension of all capillaries with consequent thickening and expansion of the alveolar septums. No fibrosis was apparent.

In summing up our findings when ligation of the pulmonary artery was combined with resection (crushing) of the phrenic nerve, we found no deformity of the chest even after four and one-half months of careful observation. Roentgen-ray examination during the first and second months revealed a certain circumscribed deformity resulting from the

67. Von Basch: Klinische und experimentelle Studien aus dem Laboratorium, von Prof. von Basch **1**:171, Berlin, 1891.

pericostal suture which brought together the two ribs adjacent to the intercostal incision. Later the stitches became loose, allowing the chest wall to return to normal shape.

The roentgen rays revealed a temporary cloudiness of the ligated side, particularly visible the first two weeks after operation. Increased density of the lung was not a constant finding. A light area above the diaphragm marked the interposition of the right mediastinal lobe between the left lung and the diaphragm. The heart was somewhat displaced to the side operated on, mostly within the first two weeks. The later changes were due rather to the paralyzed diaphragm, which was pushing the apex of the heart upward and to the left. The gradual elevation of the diaphragm became with every month more marked, occurring rather rapidly in the beginning (first month); later, rather slowly.

In the series in which the phrenic nerve was crushed very thoroughly only for a distance of 2 cm., the anatomic continuity of the nerve being left intact, paralysis was complete for about three months. Later, a definite return of tone was observed by roentgen ray, being marked at four and one-half months. This gives us a clue to the duration of the paralysis with this modified procedure. It shows that the continuity of the nerve is essential in order that the motor nerve fibers may grow through the crushed area within a relatively short time.

Anatomic Changes: These changes in the diaphragm following resection of the phrenic nerve formed the topic of a special article on the motor innervation of the diaphragm,[68] a question still under discussion, owing to the fact that only morphologic methods have been used hitherto, without any study of degeneration and electrical irritation of the nerves in question.

The formation of adhesions between the two pleural surfaces was restricted, as in our series with ligation, to the place of ligature and its neighborhood, and to the scar of the incision on the anterior thoracic wall; the first localization resulted from traumatism by the hands and instruments (retractor) at the operation, owing to the extreme delicacy of the endothelium (Boit[69]). The remaining part of the pleural cavity showed a smooth, glistening pleural covering; a proof that no oozing persisted after the operation, giving rise to a fibrinous pleurisy with subsequent organization.

The displacement of the mediastinum and of the heart was striking. After a few days, the medial borders of the upper and middle lobes of

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68. Schlaepfer, Karl: The Phrenic as the Nerve of Motor Innervation of the Diaphragm, Bull. Johns Hopkins Hosp. **34**:195 (June) 1923; Beitr. z. Klin. d. Tuberk., Würzburg **56**:261, 1923.

69. Boit, H.: Ueber die Bedeutung und die Schädigung des Pleuraendothels bei Operation und beim künstlichen Pneumothorax, Bruns Beitr. z. klin. Chir. **93**:326, 1914.

the intact side extended over the middle line toward the ligated side, forming the same deviation described previously after ligation of the pulmonary artery alone. The right mediastinal lobe expanded to the left, being interposed between the diaphragm and the compressed ligated lung. A twisting of the heart along its suspension on the great vessels resulting from the expanding right lung was noticeable in specimens of longer standing (from three to four and one-half months). The displacement of the mediastinum with the heart from the midline, the expansion of the mediastinal lobe, compressed from below by the paralyzed diaphragm, caused a reduction in size of the lung operated on to one-quarter within a few days; i. e., to about the same size it was three months after ligation of the pulmonary artery alone. This demonstrates the effect of the permanent immobilization of the diaphragm, which produces an effect similar to that of bellows on the operated lung. The increasing elevation of the paralyzed diaphragm tends to express the blood from the lung without facilitating a new inflow into this organ, which is put to a complete rest. After from two to three weeks, these combined factors, especially the paralysis of the diaphragm, brought about a decrease in size of the ligated side to one-quarter, this diminishing slowly in the following three months to one-third. At four and one-half months, the occluded lung was one-half the size of the intact one, if the postmortem elastic contraction due to the postoperative overdistension of the one functioning lung is disregarded.

The blue-red hue of the ligated side contrasted remarkably with the light color of the intact side. The consistency was different from the beginning, the ligated side growing firmer and firmer, and containing a very small amount of air at four and one-half months. The firmness was particularly due to the chronic stasis in the hugely dilated blood vessels, partly replacing the air spaces. In the first and second week, an edema was often present, filling out some of the alveolar lumina, or the dilated capillaries compressed the alveoli, and they became partly permeable. Then the picture was in these areas for a certain time very similar to that in a hemorrhagic infarct. The consistency was very firm on examination of the gross specimen. No difference was perceptible between the upper and lower lobe.

The pulmonary artery distal to the ligature was somewhat narrowed after three months. Following ligation alone, this was visible after two months. In all instances, the lumen of the vessel was free from thrombosis. The ligature was embedded in dense scar tissue. On the intact side, after three months, the pulmonary artery showed a marked dilatation, which commenced early in the capillaries and gradually involved the smaller and larger branches of the pulmonary artery.

The bronchial artery on the side of ligation was, at three months, double the size of the vessel on the intact side. In cases of ligation of the pulmonary artery alone, this vessel showed a marked dilatation after

two months. This illustrates the bellows action of the diaphragm, facilitating the in and out flow of blood through the bronchial artery and the pulmonary veins.

Microscopically, we saw in the first week a transudation through the distended capillary wall, some of the alveoli being filled with a serous fluid mixed with red and some white blood corpuscles. The alveolar epithelial cells were proliferating, partly desquamated into the alveoli and there mixed with the red corpuscles. In some areas, the capillaries obliterated the alveoli; in other areas, some scattered hemorrhages into the alveoli occurred, the picture becoming very similar to a hemorrhagic infarct. This was particularly pronounced after a week. In the second week, spindle-shaped cells proliferated around the bronchi, and the perivascular spaces and the capillaries within the septums.

At two weeks, most of the alveoli were empty; some contained cellular detritus and macrophages. In some areas away from the larger bronchi and especially in the lower lobe, strands of cellular connective tissue appeared. These strands altered the uniform picture, dividing the alveoli into islands. In the alveoli, the engorgement of all the small blood vessels and of the capillaries was still very conspicuous. In some areas of the upper lobe remote from the paralyzed diaphragm, these strands were just appearing. The difference between the upper and the lower lobe was pronounced, the changes being more advanced in the lower parts adjacent to the immobilized diaphragm.

At three weeks, the strands of young connective tissue were very definite, the spindle cell proliferation and the capillary dilatation controlling the picture.

At two months, the increase of this connective tissue and the engorgement of all blood vessels and capillaries were conspicuous, the difference between upper and lower lobe still being marked.

At four and one-half months (135 days), these strands became thicker. Now smaller lobules divided the primary one into sublobules encircling islands of alveoli with dilated blood vessels. Only a few alveolar epithelial cells were seen at this stage. The upper lobe was less advanced in this process of fibrosis, the dilatation and tortuosity of all blood vessels being predominant.

An individual variability in the degree of connective tissue formation was visible through the whole series. In many cases, this process was more pronounced at an earlier date than in tests of longer standing.

Weigert stains showed a marked increase in elastic fibers at the second month, becoming more pronounced with time. This hyperplasia and hypertrophy was first visible within the walls of the smaller blood vessels and was proportional to the degree of stasis, as proved by the series with immobilization of the diaphragm. Within the strands of fibrous tissue outlining islands of alveoli, numerous elastic fibers were seen running in a parallel direction.

The difference in the intact side was striking. Here we found through the whole series great dilatation of all the blood vessels, particularly of the capillaries in the alveolar septums. No signs of connective tissue proliferation was noticeable.

DISCUSSION OF THE EXPERIMENTAL FINDINGS

Anatomic Changes.—Within a few hours after the ligation of the pulmonary artery, Bruns and Sauerbruch [35] found a fibrinous membrane, gluing the two pleural sheaths together. After eight days, a complete obliteration of the pleural cavity was noticed, including also the diaphragmatic surface. Kawamura,[37] in analogous experiments, made the same observation. In all our specimens, we were able to trace adhesions back to some mechanical traumatism of the delicate pulmonary and parietal pleura at the time of operation. We were never able to find a complete obliteration of the pleura. The adhesions were always restricted to two places varying only in extent: (1) the region of the hilum and along the neighboring mediastinal pleura, due to mechanical trauma when this region was exposed for the ligation; (2) along the incision on the thoracic wall, resulting from the injured parietal pleura (raw surface).

In our rabbit series, the adhesions were partly local; in one specimen of long standing (three and one-half months), they were general and caused a huge dilatation of the main bronchus. As demonstrated in the specimens of short duration, absolute dryness of the field of operation was difficult to obtain. The time for operation was limited. Persistent oozing was responsible in these cases for the extensive adhesions leading to a complete obliteration of the pleural cavity.

A general synechia of the pleura can be explained only on the basis of mechanical or chemical traumatism of the pleura. If exposure to air for a certain length of time alone is sufficient (Boit [69]) to produce necrosis of the pleural endothelium, pulling and touching with dry gauze during the operation will have the same effect. Chemical irritation may be caused by oozing (of blood) into the pleural cavity after the operation. Any slight infection (contamination) will also cause a fibrinous pleurisy. This sudden intensive reaction of the pleura following the operation is the result of a complicating agent, and does not depend on the ligation itself. The presence or absence of extensive adhesions on the side operated on explains also another difference in our findings and those of Bruns and Sauerbruch and Kawamura: the thickening of the pulmonary pleura resulting from the organization of the general unilateral fibrinous pleurisy, absent in our series. After four and one-half months, the pulmonary pleura showed no thickening even microscopically except at the circumscribed places of adhesions. Bruns and Sauerbruch laid great stress on the fact that the pulmonary

pleura was several millimeters thick after from 6 to 8 weeks. Sauerbruch called this process leading to the obliteration of the pleural cavity and thickening of the pleura a chronic inflammatory condition of the pleura. The fact that Bruns and Sauerbruch never found an exudate excludes an infectious origin for those adhesions. Mechanical traumatism or slight oozing cannot be excluded, as we were confronted with it in our rabbit series. These pleural adhesions in Sauerbruch's series explain also the thoracic deformity observed by him after two months. The collapse of the lung after ligation of the pulmonary artery was greatly hampered by these adhesions, inhibiting contraction of the lung. No thoracic deformity was present in any of our specimens even after four and one-half months.

Bruns and Sauerbruch found the ligated side dark red just after the operation and also later. This was also the finding in our series, as a result of the chronic stasis. The size of the lung operated on was found by Bruns and Sauerbruch considerably reduced even after ligation alone (in one week's time).

The consistency was much firmer, so that the organ did not float. In our series, the immediate reduction in size was only remarkable when the phrenic nerve was cut at the same time. Following ligation alone, the reduction in size was gradual, to one-fourth after four and one-half months. With phrenicotomy, the reduction was about the same within a few days, increasing up to four and one-half months to one-half the original size. In our rabbit series, the reduction was striking after three and one-half months. We must bear in mind that the real difference is a greater one owing to the fact that the distended intact side contracted when the pleural cavity was opened, even with the trachea closed. The other authors do not mention at all the technic used in their necropsies. A recent experience with two analogous specimens, one treated in the usual way (described on page 19), the other by preliminary filling of the whole airway with formaldehyd, showed that the relative difference of the two sides did not vary greatly with the two methods. The regular method used in our series can be taken as a test, especially when performed uniformly through the whole series. Was the lung fully distended in Brun's experiment, in closing the chest wound, or did a pneumothorax remain? Great attention was paid to this factor in our investigations. After ligation of the pulmonary artery, it is much more difficult for the lung to expand, as demonstrated by von Basch's [67] interesting experiments. This might account for the different findings with regard to the size of the lungs.

During the time of observation, we were able to follow up the factors responsible for these changes in size on the ligated side by use of the roentgen rays. After ligation alone, the only movable structures which gave way to the constant push of the compensatory dilatation of

the intact lung were the mediastinum and heart. The displacement became noticeable at the end of the first week. In dogs and rabbits, an unusual displacement, due to an anatomic peculiarity, resulted from the expansion of the medial right lower lobe, which after operation on the left lung was displaced to the left between the diaphragm and the left lung. As time passed, the mediastinum moved slowly further to the side of operation. The diaphragm stayed at the same level on both sides.

When the diaphragm was paralysed at the time of ligation, the findings were quite different. To the mediastinum as a movable structure was added the diaphragm, which rose higher and higher as it atrophied, thus becoming the most efficacious agent for the compression of the ligated lung. In the rabbit series observed over a period of 109 days, the displacement of the mediastinum was quite remarkable, and there was simultaneous displacement of the heart. The diaphragm remained at the same level, probably as a result of the interposition of the mediastinal lobe. This gradual rise of the paralyzed diaphragm was very marked in the dog series, being quite pronounced at the beginning and later increasing slowly, but becoming more effective than the displacement of the mediastinum. As the diaphragm rose, it pushed up the apex of the heart. The expanded right lung tended to rotate the vertical axis of the heart to the left side.

In the series in which the phrenic nerve was only crushed, the tone of the diaphragm returned gradually within from three to four months. The duration of the paralysis varies with the length of the nerve crushed.

The difference in consistency of the two lungs was striking in our series, the ligated side being much firmer, as previously found by Kawamura. In no instance did the ligated side float. Special effort was made to discover any possible difference in the upper and lower lobes of the ligated side. All the lobes showed the same firmness. Gross examination did not reveal any differences. Neither was there any difference to be made out, on gross examination, following phrenicotomy. Chronic stasis with reduction of the airspaces was the main factor in this altered consistency.

The bronchial arteries showed a striking difference on the two sides. After two months, in the series of ligation, the vessel of the ligated side was considerably larger than on the intact side. After four months, it was more than from twice to three times the caliber of the corresponding side. If phrenicotomy was added, the difference was not conspicuous after two months. At three months, it was about twice the size on the side operated on. At four and one-half months, it was somewhat larger than at three months.

The piston-like action of the diaphragm, the most important muscle of respiration, maintained after ligation of the pulmonary artery a

continuous circulation through the bronchial artery, pulmonary arterioles, capillaries and pulmonary veins, thus diminishing the stasis in the lung. When the action of the diaphragm was suppressed by phrenicotomy, the resultant stasis was more pronounced. This rendered difficult the development of this bronchial-pulmonary circulation and thus postponed the consequent dilatation of the corresponding bronchial artery.

We studied also the size of the left and right pulmonary artery at the time the animals were killed. At two months, when ligation alone was performed, at three months when combined with phrenicotomy, the diameter of the artery distal to the place of ligation was narrowed, becoming more and more marked in specimens of longer standing. The more rapid development of a bronchial artery-pulmonary vein circulation after ligation alone, owing to the action of the diaphragm, caused a better emptying of the blood in the larger pulmonary arteries, thus diminishing the existent stasis. This facilitated a contraction of the vessel wall distal to the ligation. By the greater stasis, which followed ligation combined with phrenic nerve resection when continued for a longer period of time, the bronchial artery circulation was hampered. This greater stasis kept these vessels open and counteracted a secondary contraction of their wall. Later (four months), this contraction of the ligated pulmonary artery became effective also in its branches.

Through the whole series, the lumen of the ligated pulmonary artery was free from clot beyond the point of ligature. The intima was smooth four months after simple ligation. The stump of the ligated artery had the same caliber as that of the corresponding one on the other side. In the series with phrenicotomy, a distinct difference of the vessel of the intact side was shown after three months and was more pronounced after four and one-half months. A dilatation on the intact side was present. We were dealing with a gradual dilatation of the vessel wall extending backward from the primarily dilated capillaries as observed in the bronchial system of the side operated on. The dilatation of the intact pulmonary artery did not take place simultaneously in both series. It was more pronounced when the phrenic nerve was cut.

The microscopic changes are most important in an anatomic description. They give us an explanation of the changes in the lung after ligation, confirm the gross-findings and help us to explain the physiology of respiration under the new conditions.

In the first week, Sauerbruch and Bruns did not find any changes at this early stage. Kawamura noticed, as we did, an extreme degree of stasis setting in immediately after ligation, with a subsequent proliferation of the alveolar epitheliums. A result of the stasis occurring within

the first few days was a serous transudate partly filling the alveoli. In some areas, they were filled with blood. The capillaries in the septums were more or less distended, sometimes to so great an extent that, at the end of the first week in some areas, they almost touched each other, thus replacing the air space. This process was not so pronounced if ligation alone was performed, as seen in some specimens. This proves the great influence of the diaphragm as a piston acting on the lesser circulation. After its paralysis, the stasis in the lung became much greater, especially in the lower lobe. At the end of the first week, we had in some areas of our sections a picture very similar to that in a hemorrhagic infarct. The alveoli were filled partly with well preserved, partly with disintegrated blood corpuscles. The nuclei of the alveolar epithelium were in the main well stained. In a few places, they stained faintly. In other areas of the same section, we found the alveoli free, with some desquamated epithelial cells. Some of these cells were filled with blood pigment. The borderline between these areas was very irregular and abrupt. The stage with apparent hemorrhagic infarction had always developed by the end of the first week. Later, the alveoli contained fading red blood corpuscles and phagocytic cells partly filling the air sacs. The alveolar septums exhibited proliferation of their epithelium.

Were we dealing with an hemorrhagic infarct? Undoubtedly, we obtained in our cases a stage in which in circumscribed areas, a permeability of the capillaries, with a blood extravasation, resulted from the extreme stasis. These circumscribed areas were restricted to those places where the establishment of a collateral nutritive blood supply through the bronchial artery (tracheoesophageal artery; esophageal artery; pericardiacophrenic artery; mediastinal artery [Küttner [34]]) took a certain time. Finally, this circulation through the bronchial artery, pulmonary capillaries and veins became established. These hemorrhages into the alveoli (Stauungsdiapedese [Cohnheim]) were due to the stasis, perhaps to a back flow into the venules, with simultaneous nutritive changes in the vessel wall, facilitating its permeability. We explained these pseudoinfarcts on a purely mechanical basis as a result of the extreme stasis. The presence of infection was ruled out by negative bacterial stains. In the sections of the upper lobe, the areas were more extensive. This extravasated blood was taken up by proliferating alveolar epithelial cells and macrophages. After the second week, none of our specimens showed any signs of scar formation or necroses. This is only explainable on the basis that the tissue remained alive during this short period of undernutrition with blood extravasation by diapedesis. Presence of heart weakness or infection in the alveoli would probably have caused a true hemorrhagic infarct

(Fujinami,[70] Zahn,[71] Grawitz,[72] Orth [73]) bringing forth a permanent derangement of the blood supply in these areas. Necrosis and subsequently a fibrous scar, would show the result of such an incident. Normal heart action and absence of infection permitted some areas of hemorrhagic pseudoinfarction to recover after from five to seven days without concomitant necrosis of the lung tissue; and there was a complete recovery from this effect of extreme stasis. The collateral nutritive blood supply from the bronchial artery offset the effect of this preliminary stage of a hemorrhagic infarction.

After one week, Kawamura mentions a fibrous tissue growth along the blood vessels and the bronchi. We cannot endorse this statement at such an early date after ligation alone. Proliferation of the alveolar epithelial cells is the dominant feature in the first weeks in those areas.

At from ten to fourteen days after the ligation combined with phrenic resection, we obtained changes similar to Kawamura after one week. Along the smaller blood vessels and the capillaries, spindle cells proliferated, arising from the adventitial tissue. The dilatation of all the capillaries and arterioles was still conspicuous. This hyperemia was also the predominant feature after ligation alone. After immobilization of the diaphragm, the fibrous tissue proliferation was so pronounced that, at from three to four weeks, strands were visible, altering the uniform picture by division of the alveoli in lobules. This finding was particularly well demonstrated in a 20 days' specimen (rabbit) in which ligation was combined with phrenicotomy. These spindle cells developed in this new connective tissue formation, a reaction in the presence of a chronic stasis, a phenomenon analogous to that seen in all cases of chronic congestion in parenchymatous organs (liver, pancreas, kidney). At three weeks, these spindle cells dominated in the alveolar septums wherever the diaphragm was paralysed. This process of fibrosis was slowly progressive, being more marked in the lung tissue adjacent to the paralysed diaphragm than in the upper lobe, thus proving again its relationship with the degree of the chronic stasis.

After simple ligation alone, we found, even after two months, no strands of fibrous tissue such as are recorded at one month after combined ligation and phrenicotomy. The dilatation of the blood vessels and the capillaries formed the main picture. The alveolar epithelial

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70. Fujinami, A.: Beiträge zur Entstehung der hämorrhagischen Infarkte der Lunge, Virchows Arch. f. path. Anat. **61**:152, 1898.

71. Zahn, F. W.: Ueber die Folgen des Verschlusses der Lungenarterien und Pfortaderäste durch Embolie, Verhandl. d. Gesellsch. deutsch. Naturf. und Aerzte **69**:9-11, 1898.

72. Grawitz, P. A.: Ueber die hämorrhagischen Infarkte der Lungen. (Virchowfestschrift), Berlin, 1892.

73. Orth: Verhandl. d. Gesellsch. deutsch. Naturf. und Aertze, Brunswick, 1892.

cells, increased in number, were still prominent. The rabbit specimen at three and one-half months (109 days) was complicated by diffuse pleural adhesions distending the main bronchus. But even so, an extensive fibrosis, with large strands of fibrous tissue, had replaced the alveolar structure of the parenchyma to a great extent. These findings corresponded to analogous changes observed on dogs with phrenicotomy.

It is noteworthy that throughout these sections of different ages the fibrosis was less advanced in the neighborhood of the larger bronchi, owing, no doubt, to a lesser interference with circulation here.

At four and four and one-half months, the difference between ligation alone and ligation with phrenicotomy was striking. After ligation alone, the proliferation of the connective tissue around the capillaries brought forth a marked enlargement of the alveolar septums. The alveolar epithelial cells were few in number and partly faintly stained. Along the blood vessels and in the peribronchial tissue, a thickening due to fibrous tissue growth was visible; but we did not find trabeculation by compact strands of young fibrous tissue, such as was observed within three weeks after the combined operation. The dilated capillaries were still present; a sign that marked stasis still existed.

When ligation was combined with resection (crushing) of the phrenic nerve, we found the fibrosis more advanced in the lower lobe, forming strands of connective tissue bringing the smaller blood vessels and bronchi in closer contact. Encircled by these strands, the alveoli formed islands with dilated capillaries and adventitial cells in proliferation.

At four months, in both series, the alveolar epithelium had apparently partially disappeared. We were dealing with connective tissue surrounding spaces which were formerly air sacs. These spaces seemed to be outlined by spindle cells of the young proliferating connective tissue. Kawamura also was impressed by this loss of epithelium. This was the last stage in the process of apparent replacement of the alveolar epithelium by fibrous tissue.

Kawamura's statement as to the atrophy of the smooth muscles in the bronchial wall is an effect of the loss of function, in the same manner as a gradual disappearance of the alveolar epithelium. On repeated examination of our sections, we could not endorse this statement. It may be that we shall be able to confirm this fact in a series of longer standing still under observation. Kawamura found the changes which we observed at four months only when phrenicotomy was added to the ligation, even after one month. He found strands crossing the lung tissue in various directions, becoming denser as time passed, especially around the blood vessels and the bronchi. Bruns and Sauerbruch speak of fibrosis and regard the late stage as identical with the con-

dition of a parenchymatous organ undergoing chronic induration. A section described in Kawamura's paper showed, two months after ligation, a very cellular uniform connective tissue without any remnant of lung tissue. The fibrosis, which Kawamura describes in his article, is much more advanced and within shorter time than in our observations. Bruns and Sauerbruch also observed a much quicker development of fibrosis. In our series, the sections after a different length of time showed a steadily advancing process of fibrosis.

Another process developing along with this connective tissue growth was the hyperplasia and hypertrophy of the elastic tissue. The latter process became evident after three months in both series.

On the nonligated side, the extreme dilatation of all the capillaries and the small blood vessels was a constant finding through the whole series. After several months, these dilatations were even more marked, the vessels becoming tortuous, with a thin wall. The absence of any connective tissue formation within the alveolar walls and around the blood vessels was in striking contrast with the condition on the ligated side. Even after four and one-half months, the picture was the same through the different series.

In the rabbit series, the specimen observed 107 days showed a marked enlargement of the alveoli on the intact side. In the dog series, this difference was equalized for the most part by the postmortal contraction of the lung when the chest was opened. But in one specimen in which the pulmonary system was filled with a bismuth suspension, the difference of the two sides was noteworthy. Signs of proliferation of the alveolar epitheliums were not visible in any section. That process will be further investigated later in another series observed for a longer period of time.

Kawamura mentions in his experiments an enlargement of all the alveoli of the nonligated side, with reduction in elastic tissue. This condition was due to the stretching of the normal fibers.

Physiology of the Lungs Following Ligation of One Pulmonary Artery.—Within the rigid chest wall above the diaphragm, the lungs occupy a limited space, with rhythmical changes according to the inspiration and expiration. The pulmonary circulation and the blood volume in the lung are factors which we have to consider. Under normal conditions, these factors are in a certain balance; through pathologic changes or experimentally, we are able to put the lung under quite different conditions. In the introduction, we summarized the observations made by different men following compression of one lung (artificial pneumothorax). An increased blood content resulted from the hampered circulation through the pulmonary artery. By ligation of the pulmonary artery, we cut off at once the total venous blood entering the organ to be arterialized in the lung, thus putting the lung

at physiologic rest. The rate of the heart beat was unchanged by ligation. This means that the same amount of blood was now pressed through the intact side; probably the cause of the elevation of pressure in the stem of the pulmonary artery as observed by Underhill.[64] The elevation varied from 25 to 60 per cent., usually showing a 40 per cent. increase. This caused a dilatation of all the arterioles and capillaries of this lung, whereby the peripheral resistance was lowered and the velocity of the blood flow increased. After from twenty to forty minutes, Underhill registered a gradual fall of the blood pressure to normal. This seems to be the time necessary for the remaining intact lung to become adapted to the new conditions. Microscopically, through the whole series, the engorgement and tortuosity of all the capillaries was marked. This reduced the air space in the air sacs, and thereby rendered the respiratory action more difficult; but a second process became effective: the expansion of the intact lung, due to the mobility of the mediastinum with the heart, expansion of the thoracic wall, and pressure on the diaphragm. This was partly an active process, resulting from the permanent dilatation of all the capillaries. Von Basch [67] showed that a system of rubber tubes wound in a slightly oblique coil about a collapsed rubber bag brought the bag to expansion when the tubes were filled with water. When more water was put into the tubes, they became further dilated and distended; and the bag expanded more and more. This illustrates the mechanism responsible for the "Lungenschwellung" following ligation in our experiment. A condition similar to emphysema resulted. In the later stages (at three months), we were able to demonstrate in rabbits and dogs a dilatation of all the alveoli. Experimentally, an analogous expansion was obtained by injecting a nonpermeable mass into the pulmonary artery. Drinker [61] found that in any emphysematous stage of the lung, the alveolar space was reduced and as a result of the stiffness of the organ the air exchange diminished. The fact that even after months we found no signs of fibrosis associated with these chronically dilated blood vessels proves that we were not dealing with stasis but that these widened channels were an adaptation to the changed physiologic conditions, increased velocity throwing through one lung in the same time the same amount of venous blood to be arterialized as under normal circumstances passed through both lungs. Ligation of the pulmonary artery with resection of the phrenic nerve or ligation alone did not alter the microscopic picture, thus proving that these changes were due to purely physiologic principles; i. e., to a compensatory mechanism of the intact lung.

The chronic dilatation of the arterioles and capillaries in the intact lung caused a gradual dilatation of the larger branches and of the stem of the pulmonary artery, as demonstrated in our specimens of three months' standing. Marked hypertrophy and dilatation of the right

ventricle were not visible after this time. This fact will be followed up in a more extended series now under observation.

According to Kawamura and Underhill, no changes in heart rate and pulse were noticeable. This was also our observation in the majority of the cases. In a few instances, we found a slight increase of the rate, which lasted only while the blood pressure in the pulmonary artery was elevated.

The increase of the respiration rate observed after the operation was so variable in the different dogs that it is difficult to tell how much was referable to pain in the chest wound. During operation, the respiration was maintained by means of intratracheal insufflation, which made observation during anesthesia impossible. Later, the factor of pain plays an important rôle, as is proved by the great variability of this symptom in the different dogs, the rate sometimes becoming normal within the first twenty-four hours. Dyspnea was never noticed in our experiments. Kawamura states that he has never observed a dyspnoetic stage such as is mentioned in Sauerbruch's and Bruns' observation, who state that it was only of a few minutes' duration, occurring immediately after the ligation. With our form of anesthesia, it was impossible to observe such a fact. Probably we are confronted here with a reflex mechanism following ligation.

Ligation of the pulmonary artery causes a sudden accumulation of blood in the lung operated on, the venous blood being diverted to the intact side. A certain amount of the blood filling the arteries, capillaries and pulmonary veins is unable to reach the left auricle. If phrenicotomy is added, this process is much more pronounced, as the piston-like action of the diaphragm for the expression and refilling of this spongelike parenchymatous organ is thereby elicited. The diaphragm is the most important muscle of respiration regulating this mechanism. After ligation the "sponge" is not emptied so thoroughly as before. The reduced amount of blood entering the left auricle diminishes temporarily the output of blood into the systemic circulation. This lowers the pressure in the systemic circulation immediately after ligation, as proved by Dr. Kolls,[74] from the physiologic department of the Johns Hopkins University, with sphygmomanometric readings made during our experiments. This drop diminishes within fifteen minutes to two-thirds, the pressure gradually coming up to normal. Probably there is a reflex mechanism which brings to a balance again the total blood volume in the two circulations. Contraction in the splanchnic area may be this factor.

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74. Kolls, A. C.: Continuous Blood Pressure Tracings in Man; An Apparatus, J. Pharm. & Exper. Therap. **15**:433 (July) 1920; Indirect Method for Determination of Blood Pressure in Unanesthetized Dogs. ibid. **15**:443 (July) 1920.

Underhill injected gum-solution intravenously, thus increasing the output of the heart. This was followed by elevation of the blood pressure in the carotid artery. Fall of blood pressure in the carotid artery of mammals after ligation of the pulmonary artery was explained by Underhill as due to a poor condition of the heart unfitted for strain. This statement is true if a permanent drop is referred to; a temporary drop immediately after ligation is physiologic.

After ligation of the pulmonary artery, more especially pronounced when phrenicotomy was added, stasis in the lung resulted. At the end of the first week, the picture was somewhat similar to that in a hemorrhagic infarct. By diapedesis, the blood entered the alveolar spaces. But in the absence of heart weakness and infection, the undernutrition of the tissue was only a temporary one. A collateral circulation through the bronchial artery, the pulmonary arterioles and capillaries into the pulmonary veins became effective, eliminating all damage resulting from the transient vascular disturbances. The higher pressure in the bronchial artery (110 mm. of mercury in dogs [McLeod [75]]) in proportion to 20 mm. of mercury in the pulmonary artery (Stewart [76]) facilitated this process. Although this nutritive blood supply kept the organ alive, a chronic congestion persisted, with a subsequent fibrosis.

A sequel of the development of the new circulation through this lung was the gradual dilatation of the bronchial artery and its branches, first noticed at three months following ligation, and at four months when resection of the phrenic was added.

Peripheral to the ligation of the pulmonary artery, a contraction of the vessel wall was observed, setting in after two months in cases of ligation alone, in which the stasis was less marked. Three months was necessary in the parallel series with phrenicotomy.

CONCLUSIONS

Sauerbruch's statement in his monumental work on thoracic surgery, that the expectations from ligation of the pulmonary artery were in vain as this procedure was helpful only when combined with other therapeutic measures, is at least premature. His personal experience seems to indicate that great clinical improvement can be obtained with this procedure. The two cases cited above from van Voornveld and Wilms demonstrate that in very advanced cases of unilateral lung tuberculosis, even with cavity formation (bronchiectasis or abscess), this procedure offers a bright outlook, encouraging us to go further.

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75. MacLeod, J. J. R.: Physiology and Biochemistry in Modern Medicine, Ed. 2, C. V. Mosby Company, St. Louis, 1920, p. 126.

76. Stewart, G. N.: A Manual of Physiology, New York, W. Wood & Co., 1910, p. 108; Pulmonary Circulation Time; Quantity of Blood in Lungs and Output of Heart, Am. J. Physiol. **58**:20 (Nov.) 1921.

Ligation of the pulmonary artery combined with resection of the phrenic was in all our experiments in harmony with the statements of previous experimenters and of clinicians. The operation is without any noticeable shock. No change of rate of the heart beat or respiration was observed. A temporary elevation of the blood pressure in the remaining pulmonary artery, of short duration, with a simultaneous drop of pressure in the systemic circulation, were the main features of this operation. The one intact lung takes up the whole respiratory function and expands by pushing the mediastinum with the heart toward the operated side. With the gradual elevation of the paralysed diaphragm, the ligated, diseased side is compressed more and more, the secondary contraction of the fibrosing organ being thereby facilitated. Cases of unilateral malformation, with the mediastinum as the only one movable structure, prove that a great expansion of the one intact lung can take place without any chest deformity in spite of the displacement of mediastinum and diaphragm (Rohmer & Borchardt,[43] Recklinghausen,[77] Schuchardt [78]).

In any case of unilateral chronic inflammation of the lung, with evidence of a certain general resistance as manifested by fibrous tissue formation around the foci of infection, ligation of the pulmonary artery combined with resection of the phrenic nerve is very promising.

This procedure, by putting the lung to a permanent rest by direct action, induces a beneficial fibrosis whereby the foci of infection are permanently controlled. Chronic unilateral tuberculosis heals without any auxiliary operation. Other forms of chronic inflammation of one lung, as abscess, bronchiectasis, mycosis of any kind, may necessitate a secondary eradicating procedure. Ligation of the pulmonary artery with resection of the phrenic nerve may prove to be the preliminary operation of choice in these cases. This operation, causing no greater shock to the emaciated patient, whose resistance is reduced by disease of long-standing, will be a safer measure preliminary to a second stage lobectomy or pneumectomy. Knowing the underlying anatomic and physiologic principles following ligation of one pulmonary artery without and with resection of the phrenic nerve, we must build up its applicability to clinical work. The few experiences recorded in the literature and our experimental findings urge further study of this procedure for the sake of a large group of patients with chronic advanced unilateral inflammatory lung conditions.

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77. Recklinghausen: Handbuch der allgemeimen Pathologie des Kreislaufes und der Ernährung, Stuttgart, 1883, p. 315.

78. Schuchardt, K.: Hochgradige Atrophie (inveterierte Atelectase) der linken Lunge mit kompensatorischer Hypertrophie der rechten Seite, Virchows Arch. f. path. Anat. **101**:71, 1885.

GENERALIZED CISTERNAL ARACHNOIDITIS SIMULATING CEREBELLAR TUMOR: ITS SURGICAL TREATMENT AND END-RESULTS

GILBERT HORRAX, M.D.
Associate in Neurologic Surgery, Peter Bent Brigham Hospital
BOSTON

Conditions that simulate brain tumors so closely as to be mistaken for them are by no means rare. They have been classified by some as "pseudotumors." Certain of them demand prompt surgical relief for the same reasons that tumors do, if vision is to be preserved and discomforts alleviated. Among them are certain forms of chronic or subacute arachnoiditis, to which attention is to be called in this communication.

The condition of chronic arachnoiditis has been designated variously as (1) "chronic serous arachnoiditis," a generalized process, and (2) "chronic circumscribed" or "adhesive" or "cystic arachnoiditis," when the condition has been localized. The latter process appears definitely to be the sequel of a meningo-encephalitis that has left a more or less circumscribed area of adhesions between the arachnoid and the underlying patch of atrophied cortex, with the formation of an arachnoid or pseudocyst. Similar lesions have been encountered both at operation and at necropsy over almost every portion of the cerebrum, cerebellum and spinal cord. With these localized lesions, whether over the brain or cord, we are not particularly concerned.[1]

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1. The beginning of our knowledge of chronic localized arachnoiditis in its various forms coincides with the time when operations on the central nervous system were first undertaken, as by far the larger number of reports are those in which it was recognized at operation. However, the earliest description of the localized process was at postmortem in a case, described in 1898 by Schlesinger (Beiträge zur Kenntnis der Rückenmarks- und Wirbeltumoren, Jena, 1898, pp. 46, 162), in which there was found only a collection of fluid in the spinal arachnoid to account for the patient's symptoms, which were those of a tumor of the cord. This author found a "cyst containing clear fluid" lying on the anterior surface of the cord beneath the dura, just below the cervical enlargement. In 1903, Spiller, Musser and Martin (Univ. of Pennsylvania M. Bull., March and April, 1903) detailed a spinal case in which operation was performed with complete subsidence of all symptoms. This, the first operative case on record, aroused great interest, and since then there has been a gradually increasing recognition of this form of the condition, commonly known as chronic circumscribed arachnoiditis, in respect to both the spinal and cerebral meninges. Most of the early articles appeared in the German literature, and there have been several comprehensive reviews of the subject in that language, notably those by Mendel and Adler (Berl. klin. Wchnschr. **45**:1596-1602, 1908),

The generalized form of arachnoiditis was first described by Quincke in 1893 under the name of "meningitis serosa," and another treatise by the same author on this and allied conditions, appeared four years later.[2] He divided the cases into acute and chronic types and, in general, the clinical symptoms were those of increased intracranial pressure with fever, which was often high in the acute forms of the disease. The differential diagnosis from tumor, abscess, and purulent and tuberculous meningitis, had to be made in each instance, and sometimes was extremely difficult. Such differentiation was determined largely by examination of the cerebrospinal fluid as obtained by lumbar puncture, since clinical studies were always confusing. If the fluid contained no pus or tubercle bacilli, but showed an increased amount of albumin, and if all symptoms were relieved for a considerable period of time after one or more punctures, the diagnosis of serous meningitis was believed to be established. A few cases came to postmortem, but these showed no changes in the meninges, a fact which the author did not regard as invalidating the diagnosis.

Muskens of Amsterdam (Deutsch. Ztschr. f. Nervenh. **39**:421, 1910), Nonne (Die allgemeine Chirurgie der Gehirnkrankheiten **2**:105-152, 1914) and Schultheiss (Inaug. Diss., Wiesbaden, J. F. Bergmann, 1919). Spiller (Am. J. M. Sc. **137**:95, 1909) read a paper in 1909 on the subject of the spinal form of serous meningitis, in which he referred to the case which he had reported with Musser and Martin in 1903, stating that this case was the only one on record up to the year 1909 in the United States. He also stated in this paper that the patient previously reported was alive and well six years and five months after operation. The earliest reference to this subject in British literature was a clinical lecture by Sir Victor Horsley (Brit. M. J. **1**:513, 1909) in 1909. He reported twenty-one cases of "chronic spinal meningitis" in which local collections of fluid, instead of presupposed tumor, had been found at operation. As stated before, the localized type of arachnoiditis may occur over any portion of the brain or spinal cord. There are, however, certain areas of special predilection, or, at least, areas where the clinical symptomatology is of such a localizing nature as to lead to the recognition of the condition by operation. Such areas include the spinal cord in general, the rolandic zone and possibly the cerebellopontile angles, where a local process following otitis media may occur. Such a localized collection was recorded in the report of a case by Placzek and Krause (Berl. klin. Wchnschr. **44**:911-918, 1907). Their patient had very marked cerebellar incoordination, together with signs pointing to both cerebellopontile angles. At operation the only lesion disclosed was an encysted collection of clear fluid lying beneath the right cerebellar hemisphere. The patient made a complete recovery, but too short a time had elapsed between the time of operation and that of the report to be sure of the end-result. Oppenheim and Borchardt (Deutsch. med. Wchnschr. **2**:57-61, 1910) detailed three years later a somewhat similar case in which operation was performed with success, not, however, until the patient's vision had become seriously impaired from her choked disks, while being given a prolonged course of mercury and iodid.

2. Quincke: Ztschr. f. Nervenh. **9**:149, 1897.

In 1899, Seiffer[3] reported a case in which the diagnosis of serous meningitis, obviously of the generalized form, seemed quite certain. He, like Quincke, stressed the difficulties of differentiating the condition, and again emphasized the value of lumbar puncture. Seiffer referred to an article by Bönninghaus who, in 1897, reviewed the acute form of the condition, and came to conclusions similar to those held by Quincke regarding it. From the time of these early references, other articles and reviews of the subject have appeared at intervals, but the greatest portion of the literature has been devoted to the circumscribed process, referred to in Footnote 1.

The generalized condition, however, is apparently quite a distinct entity. In the cases that form the basis of this study, such examination as could be made at the time of operation revealed a thickening and grayish opacity of the arachnoid forming the large posterior cistern over the cerebellum, the cistern often being greatly enlarged. In the five fatal cases the arachnoid thickening of the basilar cisternae as well as that overlying the cerebellum was present also. The process produces a blocking of the cerebrospinal fluid system, giving an internal hydrocephalus, and the filling up of the cisternae of the posterior fossa dominates the picture. We have therefore termed the condition generalized cisternal arachnoiditis. The neurologic findings almost invariably give the localizing features of a cerebellar lesion simulating tumor.

There has never been recorded, so far as I can discover, a series of proved or presumed chronic arachnoiditis cases in which the end-results over a considerable term of years have been available.[4]

REPORT OF CASES FROM THE PETER BENT BRIGHAM HOSPITAL

During the ten years just elapsed, which represents the Brigham Hospital's first decade, there have been recorded in Dr. Cushing's service 1,264 patients with a tentative diagnosis of brain tumor. Of these, 676 have been verified as tumor by examination of tissues secured either at operation or at necropsy. Of the other 588, a large number, of course, have no doubt had tumors, but no pathologic verification has been possible. Likewise there have been a considerable number that have been classified merely as tumor suspects.

There has been, however, a certain group, all of whom have presented outspoken tumor symptoms, but at operation no tumor was demonstrable. In many such cases showing symptoms pointing toward

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3. Seiffer: Charité-Ann. **24**:644, 1899.

4. It may be said that many of the cases of arachnoid cysts of the cerebellopontile angle reported in the literature as having been encountered at operation probably represent an accumulation of fluid that overlies an acoustic tumor which has been overlooked, and the opening of the cyst may give marked relief.

the cerebellum as a localization of the process, a suboccipital exploration disclosed the general features of a cisternal arachnoiditis, which we have already detailed. In some instances a portion of the cisternal membrane has been removed for pathologic study, and these tissues, as will be recorded later, have shown evidences of chronic, inflammatory thickening.

Five patients in this group have died at intervals of a few days to two years after operation, and of these four have come to necropsy. Three of these specimens showed a definite gross and microscopic chronic arachnoiditis, and two of them showed also sclerotic changes in the cortex, evidencing an accompanying encephalitis. The other was reported by Bailey [5] in 1920. This case was studied exhaustively by special staining methods, and was definitely a leptomeningo-encephalitis. In the remaining cases, therefore, if there was no histologic study of the arachnoid, but the operation disclosed the appearances of a probable inflammatory process rather than tumor, and if in addition the patient has lived a considerable time, i. e., from two to ten years, with often a complete recession of symptoms or at least with only slight discomforts, we have assumed that in all probability we were dealing with the type of cisternal arachnoiditis that forms the subject of this report.

There have been in all thirty-three cases of the type of condition under discussion, with symptomatology pointing toward a process in the posterior fossa. All these cases have presented general pressure symptoms, with bilateral outspoken choked disks except in a very few instances. The cerebellar symptomatology has been for the most part not pronounced, usually nystagmus, moderate ataxia, and incoordination of the upper extremities, a little unsteadiness in walking or in standing in the Romberg position, and in some instances, involvement of the fifth, seventh, or eighth cranial nerves, indicating one or the other cerebellopontile angles.

In going over the records of these patients, it became evident at once that they should be considered in three distinct groups: (1) acute or subacute cases, (2) chronic cases and (3) cases in which there was a preceding history of otitis media, which was apparently the etiologic factor.

GROUP 1.—*Acute and Subacute Cases.*—We have placed in this class nine of the thirty-three cases in all of which the onset of illness ranged from fourteen days to three months before admission. In several of these patients the affliction commenced with extreme acuteness and an almost immediate evidence of increased intracranial pressure. One of the most striking examples, a patient who made an immediate recovery

5. Bailey, Percival: Contribution to Histopathology of "Pseudotumor Cerebri," Arch. Neurol. & Psychiat. 4:401-416 (April) 1920.

after operation and has remained in perfect health for two years and eight months, was the following:

CASE 5.—*History.*—H. C. W., a married woman, aged 24, referred by Dr. George Smith of Waterbury, Conn., had had an atack of influenza during the epidemic of 1918; otherwise her past history was unimportant. Her present illness began eighteen days before admission, Oct. 21, 1920, when she was awakened from sleep with a very severe headache in the frontal region. This headache was associated with nausea and vomiting, and numbness of both legs and of the right arm. The following day she noted some blurring of vision. Attacks similar to the foregoing occurred every other day during the next ten days. During these later attacks there was tinntius in both ear.s For the eight days previous to admission, the attacks came at irregular intervals, associated with projectile vomiting. During the last attack some deafness of the right ear was noted. At times she became semiconscious, with cerebellar dysarthria.

Neurologic Examination.—There was slight subocciptal tenderness and slight cervical rigidity. There was a coarse nystagmus to the right. Both fundi showed a high grade of choked disks, the elevation being 6 diopters on the right and 4 diopters on the left, with hemorrhages radiating from the disk margins. A positive Romberg sign was elicited at times, as well as some hypermetria of the right arm.

Operation and Result.—October 26, under ether anesthesia, both cerebellar hemispheres were exposed by Dr. Cushing, after the usual cross-bow flap reflection. When the tense dura was opened, a large posterior cistern was disclosed. From this an immense amount of clear fluid was evacuated, completely lowering tension. The arachnoid wall of the cistern was thickened and gray. This thickening of the arachnoid was present also out into the right recess, which was thoroughly investigated for tumor, none being found. The appearance and palpation of the cerebellar hemispheres was normal.

The patient made a prompt and practically uninterrupted recovery. About one month after operation she had headaches for a few days, associated with a rise of temperature to 100 F. Lumbar puncture was performed, and after this her convalescence was perfect. The fluid removed was negative for tuberculosis by guinea-pig injection; the Wassermann reaction was negative and the cell count normal.

The patient has remained in excellent health, and in addition to reporting by letter from time to time she also came to the hospital for a personal report, June 4, 1923, more than two and a half years after her operation. On that date she looked absolutely well, had no complaints, and had gone through a normal pregnancy since her illness. Her fundi showed no abnormalities except a slight residual pallor, and none of her previous cerebellar signs could be elicited.

Such an experience is naturally most gratifying, and it has been in these acute cases that the most striking results have been achieved. The following case, from the standpoint of vision, as well as other features, was completely satisfactory:

CASE 6.—*History.*—N. O., a boy, aged 13, who entered the hospital, Nov. 10, 1920, referred by Dr. P. W. Fox of New Britain, Conn., presented unimportant family and past history. The present illness began, Oct. 7, 1920, one month before admission, with generalized headaches and four attacks of epistaxis.

During the week of October 14 to 21, he became languid and somewhat unsteady on his feet. October 25, he noticed stiffness of the neck, and held his head constantly to the left side. There was some discomfort in the suboccipital region. November 1, he had blurring of vision with diplopia, and his gait became definitely staggering.

Neurologic Examination.—When the child entered the hospital he was nearly blind, although large letters could still be read with the right eye. Both pupils were moderately dilated, and reacted sluggishly to light but not in accommodation. There was a fine lateral nystagmus to right and left. The fundi showed an advanced degree of choked disks, with an elevation of 3 diopters on the right and 5 diopters on the left. Romberg's sign was positive, with a tendency to fall to the left. It was impossible for the patient to walk on account of the great disturbance in equilibrium. There was marked ataxia and incoordination of both legs in the heel to shin tests. The arms showed ataxia and hypermetria to a lesser degree. There was considerable adiadokokinesis in the left hand. Roentgen-ray examination of the skull showed slight increase of the convolutional impressions and slight separation of the suture lines. The blood Wassermann reaction was negative.

Operation and Result.—November 15, under ether anesthesia, Dr. Cushing explored both cerebellar hemispheres by the usual procedure. There was a moderate amount of tension, but the surface of the two hemispheres appeared and felt normal. A very large posterior cistern was disclosed with a thickened arachnoid wall, and a portion of this wall was removed for microscopic study. Puncture of both hemispheres was negative, and exploration of both lateral recesses showed nothing but large amounts of fluid. It was the operator's impression at the time that the condition was undoubtedly a serous arachnoiditis.

The patient made a rapid and progressive recovery with an astonishing return of vision accompanying the quick subsidence of his choked disks. On his discharge, December 6, three weeks after the operation, he could read medium-sized print with his right eye, and newspaper headlines with his left. The fundi showed no elevation of the disks, which appeared almost normal. His ataxia and incoordination were rapidly disappearing, there being still some slight hypermetria of the lower extremities. There was only slight swaying in Romberg's position.

Microscopic sections of the arachnoid removed at operation showed merely a slight thickening of the membrane.

A letter from the boy's father, dated Jan. 26, 1922, states that "he is in splendid condition, active in all outdoor sports, and enjoying life to its utmost for a boy."

Our last letter, from the patient's family physician, Feb. 19, 1923, two years and three months after operation, says: "His sight is perfect. He is going to high school every day and stands well in his studies. He is now a strapping young fellow."

In almost all the patients whom we are considering, with symptoms implicating the posterior fossa, a suboccipital exploration was carried out. There were, however, three patients, all in this acute group, on whom a simple subtemporal decompression was performed since their cerebellar symptoms were inconspicuous. It is true that we have no absolute evidence of arachnoiditis of the posterior fossa, but the neurologic findings combined with tension, increased amounts of sub-

arachnoid fluid and internal hydrocephalus made such a diagnosis most probable, since they all recovered completely and remained well between two and three years, with nothing to indicate the slightest return of intracranial pressure. The story which follows is similar to those of the other two patients on whom subtemporal decompressions were performed.

CASE 3.—*History.*—I. L., a Jewish girl, aged 19, referred by Dr. A. R. Manitoff of Revere, Mass., had a younger sister who was said to have tuberculous peritonitis. This was the only thing of importance in her family history. She herself had had an appendectomy in March, 1919, followed by general peritonitis. She also had suffered from frequent sore throats.

April 1, 1920, three weeks before her admission to the hospital, she began having stabbing pains in both temporal regions, associated with dizziness. These pains continued, and she vomited three times, April 11. On this day she noted a beginning dimness of vision. She vomited again, April 13, and headache was continuous until the 16th, after that becoming intermittent, but always brought on by resting the back of her head on a pillow. There was rapid failure of vision from April 11, until her admission, April 20.

Neurologic Examination.—Light perception only was retained in the right eye, and with the left she could barely count fingers at 18 inches. There was a slight bilateral exophthalmos. The right pupil was wider than the left, and there was some weakness of the right internal rectus oculi. The fundi showed an extreme grade of choked disks, with hemorrhages and exudates radiating from the papillae. The elevation was 7 diopters in the right eye and 6 in the left. Slight suboccipital tenderness was present; there were a few nystagmoid jerks to either right or left, and there was some unsteadiness in walking not attributable to her poor vision. Her blood and subsequently her cerebrospinal fluid Wassermann reactions were negative.

Operation and Result.—April 26, I performed a right subtemporal decompression. The dura was found to be under great tension, but on introducing a needle through the middle temporal convolution I encountered and evacuated a dilated ventricle, thus lowering pressure so that the dura could be opened widely in all directions. No surface lesion was disclosed.

There was immediate and rapid improvement in vision. May 4 (eight days after operation) she could read fine print with the left eye, and her papilledema had subsided to 3 diopters on both sides. She was discharged, May 13, with vision in the right eye 1/200+, and in the left, 20/30+. All her preoperative symptoms and neurologic findings otherwise had disappeared. Aug. 20, 1921, she reported for examination by request. Vision was normal in both eyes, while her disks were flat and showed only very slight evidence of secondary atrophy. The decompression area was not bulging or tense. She had had no headaches or other discomforts. Oct. 30, 1922, two and one-half years after operation, she reported by letter that she was still quite well in every respect.

One is reminded, in the cases just detailed, of a series of five patients reported by Foster Kennedy[6] in 1921 under the name of "acute, benign meningo-encephalitis." Kennedy's patients, however, all had "evidence of systemic infection as shown by the presence of a

6. Kennedy, Foster: Am. Neurol. A., 1921, pp. 59-63.

changed blood picture, fever and general malaise." They all had an acute course and developed choked disks sometimes as high as 6 diopters, the latter coming on late in the illness and eventually subsiding spontaneously.

In our cases the temperature in Cases 2 and 3 was normal throughout, but that of Case 1 had risen to 101 F. on several occasions before the patient entered the hospital. There was no leukocytosis in any of our cases. It might be argued that the papilledema in our patients would likewise have subsided without operation, but we did not feel justified in taking such a chance with so valuable an asset as vision at stake. Also in Case 1, death by medullary compression might easily have occurred during one of her seizures of semiconsciousness.

One more case in this group may be cited, a patient whose symptoms had progressed farther than those already given. The secondary atrophy of her optic disks prevented a restoration of vision, but her other discomforts were relieved and she was in good physical health at our last report, five years after operation.

CASE 1.—*History.*—N. T., a married woman, aged 43, admitted to the hospital, Nov. 24, 1916, referred by Dr. F. H. Lahey of Boston, presented irrelevant family and past history. Two months before her entrance, she began to have vertical and suboccipital headaches, associated with vomiting, which was projectile at times. The headaches became increasingly severe up to the time of her admission. There was progressive failure of vision, the loss being rapid and almost total during the two weeks before coming to the hospital. On several occasions she had seizures of loss of consciousness, which were apparently not convulsive and without aura. She had some spells of dizziness at times, and recently hearing had become somewhat impaired in the left ear.

Neurologic Examination.—There was lateral nystagmus, quick to the right and slow to the left. There was adiadokokinesis of the right hand and a positive Romberg sign. She balanced poorly on the left leg. She was totally blind, the pupils being dilated and fixed. Both fundi showed disk margins entirely obliterated by new tissue and edema. The vessels were embedded and tortuous, when they appeared at all, over the disks. There were extensive hemorrhages over the region of the disks, the latter being elevated 4 diopters in each eye.

Operation and Results.—Dec. 2, with ether for an anesthetic, Dr. Cushing explored the posterior fossa by means of the usual bilateral exposure. The dura was very tense, but when it was pricked there escaped a large amount of fluid from the posterior cistern. The latter was found to be greatly dilated when the dura was opened widely. The lower margins of the cerebellar hemispheres were seen to be squeezed down into the foramen magnum, compressing the medulla. No tumor was disclosed, and investigation of each recess showed no lesion.

The patient made a quick and uneventful recovery. Six days after operation it was noted that she could see shadows and count fingers with the right eye, but vision never improved beyond this point. She was discharged, December 17, with her previous discomforts entirely relieved and with complete recession of her choked disks, leaving the evidences of secondary atrophy.

Jan. 26, 1920, three years after operation, I saw the patient. She was in good general health, bright and active mentally. She walked well, in view of the fact that she was almost blind, the condition having remained about the same since she left the hospital. There was persistent nystagmus, both lateral and vertical, and some slight ataxia and intention tremor of the arms, but no other sign of cerebellar involvement. The disks were flat and the area of suboccipital exploration was not tense.

Oct. 19, 1921, almost five years after operation, I saw her again. Her condition in all respects was similar to that at the time of the previous note.

This patient illustrates not only a five year end-result, but also signalizes what we believe may often happen to the optic nerves from an otherwise benign condition, unless intracranial tension is relieved. In many cases such as this, no microscopic evidence of the underlying pathologic condition has been available; but the gross appearance at operation, coupled with the long relief of symptoms, makes the diagnosis of arachnoiditis far more probable than quiescent tumor.

The remaining five cases in this group need not be detailed. It is sufficient to say that two of the patients were quite well and one improved at our last reports, two years subsequent to their operations (Table 1). The other two died, one, a hydrocephalic child, a few days after operation, and the brain at necropsy showed no tumor but an extensive gross thickening of the arachnoid over the base. Microscopic studies confirmed the gross appearance, and in addition showed some evidence of a concomitant encephalitis.

The other patient who died was a young man who made a fine recovery for nearly a year after operation in 1921. His symptoms then recurred and the posterior fossa was twice subsequently exposed; a huge pocket lined with glistening, thick membrane was disclosed, and though efforts were made to secure drainage, they were unsuccessful and successive taps were resorted to after his discharge. He died a few months after his discharge, and the brain was forwarded for study. It showed an extensive thickening of the arachnoid around the cerebellar hemispheres and over the cerebral base (Fig. 1). There was no tumor. Microscopic studies confirmed the arachnoid thickening which had been obvious grossly.

TABLE 1.—*Acute and Subacute Cases*

Case No.	Date of Operation	Date of Last Report	Condition at Last Report	Years After Operation	Age at Time of Operation
1	1916	1921	Improved	5	43
2	1920	1920	Dead	0	8
3	1920	1922	Well	2	19
4	1920	1922	Well	2	15
5	1920	1922	Well	2	24
6	1920	1923	Well	3	13
7	1921	1923	Well	2	23
8	1921	1923	Improved	2	19
9	1921	1923	Dead	2	26

GROUP 2.—*Chronic Cases.*—In this class there have been included by far the largest number in the series; namely, nineteen out of the total thirty-three. From the standpoint of operative therapy, the results in Group 2, while not perhaps so immediately striking as in Group 1,

Fig. 1.—Generalized arachnoid thickening involving the large basilar cisternae; natural size.

have nevertheless been exceedingly satisfactory. Of the nineteen patients, seven have been termed well and nine improved over periods varying from one to ten years after operation. Three patients have died, one from sudden respiratory failure two days after operation, and another at the end of two years after having had a period of

improvement. Necropsy in the latter case verified the presumed diagnosis of arachnoiditis, as will be seen in the complete record a little later. The third was the case reported by Bailey in 1920, which, as stated, was a lepto meningo-encephalitis.

The following is a good example of one of the early patients who was in excellent health at our last report, Sept. 15, 1920, seven years after operation:

CASE 11.—*History.*—H. D., an unmarried woman, aged 28, who entered the hospital July 12, 1913, referred by Dr. George Derby of Boston, had had one brother who had previously died of a brain tumor, and one sister who was "mentally deranged." Her own past history was unimportant, save that five years before admission she had fallen on the ice, striking the back of her head, and was stunned for a few minutes. Her present illness began in October, 1908, with the sudden onset of headaches, which were at first frontal, but later suboccipital. They continued until an operation on the sphenoidal sinuses in 1909, since which time their severity and frequency were lessened until two months before admission, at which time they recurred with their former intensity. At the onset of headaches she experienced blurring of vision, and at irregular intervals had diplopia. She had been given changes of glasses by a capable ophthalmologist, with little or no benefit. Dizziness was associated frequently with the headaches, and, at times, nausea.

Neurological Examination.—There was a positive Romberg sign, considerable ataxia of the upper extremities and some unsteadiness of gait. There was lateral nystagmus to the right. The fundi showed a low grade of choked disks with blurring of the margins, hyperemia and perivascular streaking. The blood and spinal fluid examinations were negative; the white count was normal and the patient had no fever.

Operation and Result.—Sept. 19, 1913, Dr. Cushing explored the posterior fossa under ether anesthesia. The cerebellar hemispheres appeared normal, and no tumor was disclosed. The median posterior cistern was greatly enlarged, its arachnoid wall being thickened and grayish. Exploration of the left lateral recess disclosed another collection of fluid in a thickened arachnoid pocket; the fluid was evacuated. It was the operator's opinion at the time that the condition was one of serous arachnoiditis.

The patient made a good recovery, the previous symptoms becoming immediately much lessened; at the time of her discharge, October 16, they had disappeared. She continued perfectly well until March, 1915, when she had a slight recurrence of headaches and a little dizziness, which lasted only a few weeks.

Sept. 19, 1917, four years after operation, the patient wrote saying she was well and living an active life.

Sept. 15, 1920, seven years after operation, she again wrote that she was "in perfect health and head of a school."

There can be little question of the diagnosis in the case just given when the operative findings and the subsequent course of the patient are considered. A piece of the arachnoid, had it been taken for study, would no doubt have shown microscopically the customary slight thickening that has been present in many similar instances.

The next patient was also one of the early patients at the hospital, and has remained perfectly well for eight and a half years.

Case 12.—*History.*—J. F. S., a boy, aged 3 at the time of admission, April 6, 1914, referred by Dr. F. P. Broderick of Jamaica Plain, Mass., had been normal in birth and development, except that his head was thought to have been a little large. At the age of 2 years (one year before entrance), the child began having periodic headaches, associated with, and often relieved by, vomiting, and at the same time it was noticed that he held his head tilted toward the right side. Six months later his walking became noticeably unsteady, progressing to definite staggering, and three months prior to admission it was impossible for him to walk at all. Unsteadiness of both hands, but especially the right, was also noticed.

Neurologic Examination.—The head was moderately hydrocephalic, its circumference being 55 cm. Cracked pot resonance was elicited on percussion, and there was a bruit synchronous with the radial pulse over both temporal regions. The head was held tilted to the right side. Both fundi showed a moderate degree of choked disks, with some secondary atrophy. There was a positive Romberg sign and slight ataxia in the finger to nose tests with both hands. Walking was impossible.

Operation and Results.—April 17, under ether anesthesia, the cerebellar hemispheres were explored by Dr. Cushing. An unusually large posterior cistern was disclosed, from which a large amount of fluid was evacuated. No tumor was found by inspection, by puncture of each hemisphere or by incising the right hemisphere to a depth of 2.5 cm.

The child made an easy and gratifying recovery. At the time of his discharge, May 20, 1914, he had none of his pre-operative discomforts. He could walk a few steps alone, and there was only slight unsteadiness of his hands. The choked disks had largely subsided.

Nov. 8, 1922, eight and one-half years since operation, I examined the patient. He was apparently in all respects a normal and healthy boy of 11. He had never had any signs of intracranial pressure since being operated on, but for three or four years his mother said he was somewhat unsteady on his feet. At the present date there were no signs of cerebellar involvement, and the fundi were normal. This was the only time the patient came back for examination since being in the hospital.

In contradistinction to the foregoing patients, whom we have classed as "well," we may quote the following case as "improved," although with the exception of vision, which was reduced very markedly before operation, and has remained the same ever since, the patient was entirely relieved.

Case 21.—*History.*—J. C. R., a married man, aged 25, who entered the hospital, July 3, 1920, referred by Dr. C. F. Hoover of Cleveland, and whose family history was negative, for six years had suffered from attacks of furunculosis, and was subject to gastro-intestinal upsets. In September, 1919, he began to have severe frontal headaches on awakening, and at night there would be an ache in the suboccipital region. In October, 1919, he noticed that whenever he moved his head suddenly he would become blind for a moment. During this month he consulted an ophthalmologist, who discovered that he had choked disks. In December, 1919, he began having nausea and vomiting,

associated with dizziness. Vomiting caused an increase in the headache. In March, 1920, he had to stop work on account of the headaches, and in April, 1920, he first noted double vision and some blurring with the left eye. During all this time the choked disks had continued, ophthalmologists attributing the trouble to "some toxic condition." From the middle of June, 1920, until admission to the hospital, three weeks later, his eyesight failed very rapidly, and there was tinnitus in both ears.

Neurologic Examination.—There was evidence of marked intracranial pressure, with definite signs pointing to a localization of the cause to the cerebellum. Both optic disks showed an elevation of 4 diopters, with advanced secondary atrophy. There was complete embedding of the vessels in many places at the disk margins. Vision in the right eye was 20/70, and in the left, 10/200. The right pupil was larger than the left, and there was a left abducens palsy. A sustained nystagmus was present both to the right and to the left, it being slower to the right. There was moderate suboccipital tenderness. Romberg's sign was positive, and there was marked ataxia and incoordination in the finger to nose test of both arms. The gait was definitely staggering. The blood Wassermann reaction was negative, as was also the examination of the spinal fluid, which had been made at another clinic. The patient had no fever, and the white count of 13,200 was explained by the presence of a mild furunculosis.

Operation and Result.—July 8, 1920, I performed a suboccipital exploration by means of the usual bilateral flap reflection. The left lateral ventricle was tapped, and found to be greatly dilated. This lowered the intracranial tension so that the dura over the cerebellum could be opened without fear of herniation. A large posterior cistern was disclosed, its arcahnoid sheath opened and the fluid within it allowed to escape. Both cerebellar hemispheres appeared and felt normal, and punctures on either side were negative. There was a considerable herniation of the lower lips of the cerebellar lobes into the foramen magnum.

The patient made an easy recovery, and was discharged, July 30. At this time his subjective discomforts were all relieved, but there was still some ataxia of the hands and unsteadiness in gait. The fundi showed a nearly complete recession of the choked disks, but the marked secondary atrophy of course remained. Vision was about the same as before operation.

Aug. 8, 1921, one year after operation, when I saw him, his general physical condition was excellent, and his vision was good enough to allow him to get about by himself. There was still some slight unsteadiness in walking, and slight ataxia in the finger to nose tests. The lateral nystagmus continued. The optic disks showed very marked secondary atrophy, but no elevation. There was no bulging or tension of the suboccipital operated area.

Sept. 11, 1922, two years and three months after operation, a letter from the patient said that he was felling very fit and had no discomforts. His vision remained the same as it had been at the last examination.

One more case in this group may be cited, a patient mentioned previously who died two years after operation. In this instance, we have the gross and microscopic evidence from the necropsy as to the nature of the disorder.

Case 22.—*History.*—J. O., a woman, aged 39, who was admitted, Aug. 24, 1920, and whose family history was negative, had been partially deaf in both ears for six years. In February, 1920, six and one-half months before admis-

sion, she began having morning headaches, accompanied by dizziness and unsteadiness in walking. At times there was real vertigo with vomiting, these two symptoms later becoming almost constant. Her vision, and what remained of her hearing failed gradually during the six months before she came to the hospital. There had been tinnitus in the right ear for the past three months.

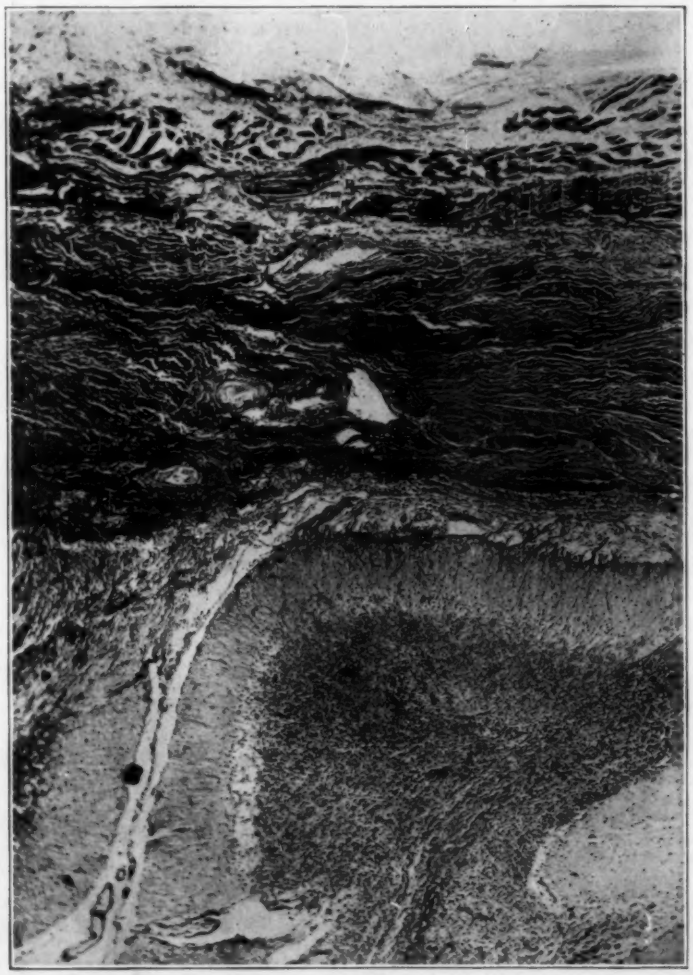

Fig. 2 (Case 22).—Extreme thickening of arachnoid membrane overlying cerebellum; adhesions between arachnoid and pia; slightly reduced from a photomicrograph × 48.

Neurologic Examination.—There was complete deafness in the right ear, and nearly complete in the left. There was a suggestion of left facial palsy. Both fundi showed a high grade of choked disks, with an elevation of 4 diopters on each side. There was sustained horizontal and vertical nystagmus, a positive Romberg sign and staggering gait. In addition, the patient showed a positive

Babinski and Oppenheim on the left, and ankle clonus on both sides. The blood Wassermann reaction was negative, and she had no fever or leukocytosis.

Operation and Result.—September 9, Dr. Cushing exposed the suboccipital region by the usual procedure. The dura over the cerebellum was moderately tense, and when it was opened a very large posterior cistern whose arachnoid wall was somewhat adherent and of an unusually thick character was disclosed. The membrane was yellowish gray, somewhat granular, and exceedingly opaque. The arachnoid over both cerebellar hemispheres was also thickened, and this thickening extended out into both lateral recesses. The nerves were seen plainly on each side, and no tumor was disclosed.

The patient improved very much after her operation, and was discharged, October 2. At that time she was relieved of headache, vomiting and dizziness, and her walking, though unsteady, was improving. The Romberg sign was negative, and the choked disks had subsided to 2 diopters on each side. She was in good spirits, and said that she had not felt so well in years.

Nothing was heard from the patient until Nov. 3, 1922, when her husband wrote in response to a letter of inquiry that she was ill at another hospital. It was then learned that she had been in this hospital for eight months with cystitis. She died, Nov. 11, 1922, and necropsy was performed the same day by Dr. Hugo Mella of Boston, who kindly brought us the material for study.

Pathologic Report.—The brain showed over the cerebellar hemispheres, and extending around over the base of the pons and medulla, the same extreme grade of arachnoid thickening that was noted at operation. Serial sections from the frontal to the occipital lobes showed no tumor.

Microscopic sections were taken from a large number of places, including the cerebrum, cerebellum, pons, medulla and basal ganglions. There was some evidence of an accompanying encephalitis, as seen by sclerotic changes at considerable depth in the cortex. The arachnoid showed over the cerebellum and the base an enormous thickening due to an increase in fibrous connective tissue (Fig. 2). There were a few small round cells, and the histologic diagnosis was chronic arachnoiditis.

It is not essential to cite fully the remaining cases in Group 2. They all conformed in a general way to one or the other of the types already illustrated, and the main facts concerning their end-result with the time since operation may be seen in Table 2.

TABLE 2.—*Chronic Cases*

Case No.	Date of Operation	Date of Last Report	Condition at Last Report	Years After Operation	Age at Time of Operation
10	1913	1922	Well	9	38
11	1913	1920	Well	7	28
12	1914	1922	Well	8	3
13	1915	1915	Improved	1	13
14	1915	1921	Improved	6	48
15	1916	1922	Improved	6	55
16	1917	1917	Improved	1	23
17	1919	1919	Dead	0	33
18	1919	1919	Dead	0	16
19	1920	1922	Well	2	34
20	1920	1922	Improved	2	36
21	1920	1922	Improved	2	25
22	1920	1922	Dead	2	39
23	1920	1921	Improved	1	26
24	1920	1921	Improved	1	22
25	1920	1922	Improved	2	13
26	1921	1923	Well	2	26
27	1922	1923	Well	1	32
28	1922	1923	Well	1	25

We now come to the last group, in which there seemed to be the rather definite etiologic factor of previous suppuration of the middle ear.

GROUP 3.—*Cases Following Otitis Media.*—In this category there have been five cases; two of the patients have remained well, and the other three improved anywhere from three to nine years after operation. In every instance the course has been extremely chronic, characterized, as might be expected, by severe labyrinthine disturbances. All five patients had rather moderate symptoms of increased intracranial pressure, the optic disks showing at most a low grade of choking, with an elevation never exceeding from 2 to 3 diopters, although in some instances there was considerable secondary atrophy.

A single case will be cited as illustrative of the others in the group, which are tabulated in Table 3.

TABLE 3.—*Cases Following Otitis Media*

Case No.	Date of Operation	Date of Last Report	Condition at Last Report	Years After Operation	Age at Time of Operation
29	1913	1918	Improved	5	38
30	1913	1922	Improved	9	26
31	1913	1922	Improved	9	52
32	1916	1922	Well	6	23
33	1919	1922	Well	3	33

CASE 29.—*History.*—A. G. M., a man, aged 38, was one of the earliest patients at the hospital, which he entered, Feb. 3, 1913. He was referred by Dr. M. Snyder of New Kensington, Pa. His family and past history were negative. Three years before admission he had an attack of tonsillitis, followed by otitis media with spontaneous rupture of the drum membrane on the right side. Shortly after his ear started to discharge he began having pains behind the right ear and in the suboccipital region. These pains were associated with severe dizzy spells, which became more and more frequent until he came to the hospital. On several occasions he was seized with a sudden dizziness and fell to the ground. For a month or two prior to admission, he had momentary spells of amblyopia, as well as nausea and vomiting associated with the dizziness.

Neurologic Examination.—There was persistent lateral nystagmus both to the right and to the left. There was slight swaying in the Romberg position. The left hand deviated to the right in the Bárány finger to finger test. He had a definitely staggering gait. The fundi showed rather low choked disks, the elevation being 3 diopters on the right side and 2 on the left.

Operation and Result.—Under ether anesthesia, February 7, Dr. Cushing explored the right cerebellar hemisphere and the right lateral recess by means of a curved flap incision over the region in question. The dura was thick and somewhat yellowish, and when it was incised a large, posterior cistern was disclosed. In the recess there was an arachnoid cyst, which contained 15 c.c. of fluid. After this fluid had been evacuated, the normal appearing acoustic and facial nerves could be seen plainly.

The patient recovered from his operation very well, and while in the hospital was quite free from his old discomforts. He was discharged, February 25.

Sept. 3, 1915, he reported by letter that he was fairly well, but still having pains in his head at times.

Sept. 3, 1918, five and one-half years after operation, he wrote that he was still having occasional pains back of his eyes, but was on the whole fairly well.

ETIOLOGY, PATHOLOGY AND TREATMENT

I have presented a series of thirty-three cases which, from the standpoint of clinical diagnosis, resembled very closely tumors of the cerebellum. All the patients reported were operated on with the presumptive diagnosis of tumor, and in none was a tumor found. Five of these patients died, two of them within a few days after operation, and the other three anywhere from several months to two years later. Of the four on whom necropsy was obtained, all showed histologically inflammatory thickening of the arachnoid membrane forming the cerebellar and basal cisternae. Of the twenty-eight patients who survived, all have been improved or were well from one to nine years after operation. In the living patients there was disclosed at operation over the cerebellum a greatly dilated posterior cistern with its thickened arachnoid membrane, which contained pent-up cerebrospinal fluid under pressure. In a few instances a piece of the arachnoid wall was removed for histologic examination, and these specimens showed nothing more than the slight thickening that was evident grossly. Such evidence, although not so conclusive as might be desired, coupled with the subsequent improvement or entire relief of symptoms over long periods of time, has convinced us that the cases were not tumor, but were in fact arachnoiditis, as surmised at the time the posterior fossa was exposed.

Whether there is usually a concomitant encephalitis, as in the case studied by Bailey, can be told only by the use of particular staining methods, which were not employed as a routine in this series. Dr. Bailey, however, was kind enough to look over the sections of the fatal cases here reported. Blocks were taken, including both arachnoid and cortical tissue, and two of these showed definite sclerotic changes in the cortex as evidence of previous encephalitis. Foster Kennedy described his five cases as "acute meningo-encephalitis"; but these patients recovered, and no histologic studies were therefore available. His patients, as already noted, had fever and leukocytosis, conditions that were present only in rare instances in our group.

It is hardly necessary to say that in all our series there was no serologic or bacteriologic evidence of syphilis or tuberculosis.

It is, of course, realized that some of our patients who were operated on only one or perhaps two years ago may yet prove to have tumor; but we have been at pains to pick out from the whole group of intracranial cases only those in which such an eventuality did not seem

likely from the operative evidence as well as from the subsequent history. In this connection, however, it is important to note that several patients who were at first arachnoiditis suspects have later died, and necropsy revealed a brain tumor. Such cases have nevertheless almost invariably, after a subtemporal or suboccipital operation, again shown decided pressure symptoms within a year, although death may not have occurred for from two to three years.

It is also true that one may sometimes find the same sort of very gray and opaque arachnoid membrane over the posterior cistern when there is an actual tumor disclosed in the cerebellum, and an arachnoid cyst overlying an acoustic tumor is of very common occurrence, so that one must not be deluded by the operative appearances alone.

Etiology.—Little or nothing can be said as to the etiology of the type of arachnoiditis under discussion except in the cases which have followed closely on an otitis media. In these patients the arachnoid of the lateral recess seemed to have been attacked by an extension inward of the process in the middle ear, a presumption that has been recognized by almost all previous writers on the subject.

As to the other cases, such causes as cranial trauma, infected contusions of the scalp, and ocular and nasopharyngeal infections have been assigned. Sir Victor Horsley mentions syphilis and gonorrhea as possible sources in certain of his spinal cases of the localized type, although there was no verification bacteriologically. Spiller said in 1909 that there was no known etiology.

Influenza and encephalitis have been mentioned as possible causes, there being some evidence from our series in favor of the latter, as already stated. It is of interest also that twelve of our twenty-eight subacute and chronic cases occurred in 1920, a year after the influenza epidemic, and a time when many cases of epidemic (lethargic) encephalitis occurred. No other etiologic evidence has been apparent.

Treatment.—The group of cases here presented have been clinically indistinguishable from tumors of the cerebellum, except in one or two doubtful instances, as noted. Exploration of the suboccipital region was therefore the procedure of choice, and in the absence of tumor, all that could be done was to open widely the arachnoid cisternae that were present, thus evacuating their contents. In the large majority of patients this was sufficient to effect an entire relief of the pressure symptoms, at least for the varying lengths of time they have been followed. We have not employed lumbar puncture as a diagnostic measure, believing the risk of a fatality from foraminal herniation of the cerebellum to be too great in patients with increased intracranial pressure.

RENAL MALFORMATION AND RENAL DISEASE*

C. HAROLD JAMESON, M.D.
ROCKLAND, ME.

Anomalies or congenital malformations of the kidney and ureter are of frequent occurrence, and abundant reports are available concerning their types and varieties. That such developmental anomalies often give rise to clinical symptoms is perhaps less generally recognized. The symptoms of disease so caused are frequently obscure and misleading, while the results of routine physical examination may be quite without significant positive value. Examination of the urine often does not supply data pointing to the urinary tract as the source of the patient's complaints. Thus, one finds that there is frequent recourse to an "exploratory laparotomy," with removal of a normal appendix, gall-bladder or salpinx, while the underlying pathology escapes notice. It is our belief that many such cases presenting obscure abdominal symptoms, in which the usual methods of diagnosis have failed to demonstrate significant pathologic processes, will be clarified if these renal anomalies are kept in mind and pyelography is employed.

EMBRYOLOGY

The pronephros and mesonephros are transitory stages in the development of the mammalian kidney, giving place finally to the permanent kidney, the metanephros. Consisting of seven pairs of segmentally arranged masses of mesenchymal tissue (nephrotomes) in which develop tubules uniting to form a longitudinal duct on either side, the pronephros forms the primary excreting duct of the embryo. While no pronephric tubules develop caudad to the fourteenth body segment, the duct itself continues to grow caudad to meet and fuse with the cloaca in embryos 4.2 mm. in length.[1] The tubules of the pronephros degenerate early, while the ducts persist as the excretory channel for the mesonephros during embryonal life, and more remotely to serve a permanent function as the outlet for the secretion of the male genital gland during adult life.

The mesonephros arises from an unsegmented mesodermal mass caudad to the tenth pair of segments, where it is represented by the nephrogenic cord extending caudad as far as the twenty-eighth segment, and lying mediad to the primary excretory duct with which its individual tubules are connected. A degeneration of these tubules cephalad con-

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* From the urologic clinic of the Peter Bent Brigham Hospital.

1. Keibel and Mall: Human Embryology, Vol. 2, Philadelphia: J. B. Lippincott Co., 1912, p. 773.

tinues *pari passu* with development of new tubules caudad, only twenty-one interrupted groups of the total eighty-three pairs persisting in the 22 mm. embryo. The upper group uniting with the rete tubules of testis or ovary form in the male the efferent ductuli of the epididymis, or in the female, part of the epoöphoron. The lower group persist in the male as the paradidymis, in the female as the paroöphoron.

The blood supply in general, or more particularly the arterial supply of the mesonephros, is of peculiar interest because of its influence on the vascularization of the metanephros, the anlage of the permanent kidney. On either side, there develop thirty mesonephric arteries, originally distributed to the excretory gland, but subsequently becoming connected with the metanephros, sex glands, suprarenals and diaphragm. With the degeneration of the mesonephros, certain of the vessels remain to enter into the formation of the phrenic, suprarenal, renal, accessory renal, external spermatic and accessory spermatic arteries. There is no pairing or segmental arrangement in the arterial configuration so that no regularity appears. Felix found the mesonephric arteries in a reconstruction of an 18 mm. embryo divided into three groups by the suprarenal body, a cranial group running dorsad, a middle group penetrating and a caudal group passing ventrad to the suprarenal body. As degeneration of the mesonephros advances, the more cephalad arterial elements drop out, while caudad from the sixteenth thoracic to the third lumbar segment all the arteries may persist as the permanent branches mentioned above. According to Felix, the fifth to the ninth or the seventh to the ninth mesonephric arteries in the angle between reproductive gland, mesonephros and metanephros form a network, the rete arteriosum urogenitale, consisting of coarse-meshed vessels from which individual vessels arborize to these three organs. Fortuitous degeneration of a particular branch is readily compensated for by some adjacent branch of the rete assuming its function. Considerable variation in the eventual vascularization and in the point of origin of the particular artery from the aorta is thus possible. The accompanying diagram is of aid in depicting the arterial supply of the mesonephros, and may also be referred to in connection with the vascularization of the metanephros (Fig. 1).

The metanephros or permanent kidney in man consists of two distinct portions; the true excretory or glandular portion and the efferent apparatus. The latter develops by an outgrowth on either side from the primary excretory duct of the embryo; the former starts from the caudal portion of the nephrogenic cord in which arise the metanephric tubules.

In embryos from 4.5 to 5.5 mm., the mesonephric duct becomes angulated before entering the cloaca, and at this point the bud of the ureter appears, growing dorsad and then cephalad (Fig. 2). Coincident

with its earliest development, the shape of the ureteric bud becomes modified by the formation of an expansion, the renal pelvis, and a cranial and a caudal tubule, further outbuddings of which form successive generations of tubules until twelve are developed. The first two primary tubules form the superior and inferior major calices. The secondary tubules opening into them form the minor calices. The tubules of the third and fourth order are taken up into the primary calices, leaving those of the fifth order, estimated as from twenty to

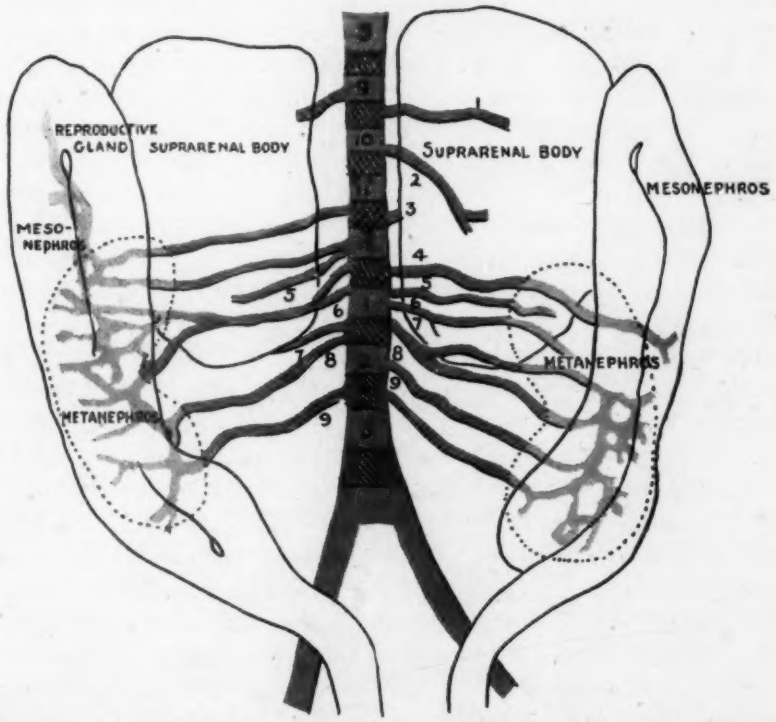

Fig. 1.—(From Keibel and Mall: Human Embryology). Reconstruction of the mesonephric arteries of a human embryo of 18 mm. The mesonephric arteries are indicated by numbers placed below them. The right, fifth, sixth, eighth, and ninth, and the left seventh, eighth, and ninth, form a network between the reproductive gland and the metanephros, the rete arteriosum urogenitale.

thirty, opening into the minor calices as papillary ducts, while the remaining orders constitute the collecting tubules which persist in the medullary portion of the adult kidney. Coincident with this budding, the ureter grows craniad, until in embryos of from 9 to 13 mm. the pelvis has reached a position in the retroperitoneal tissue dorsad to the mesonephros in the second lumbar segment.

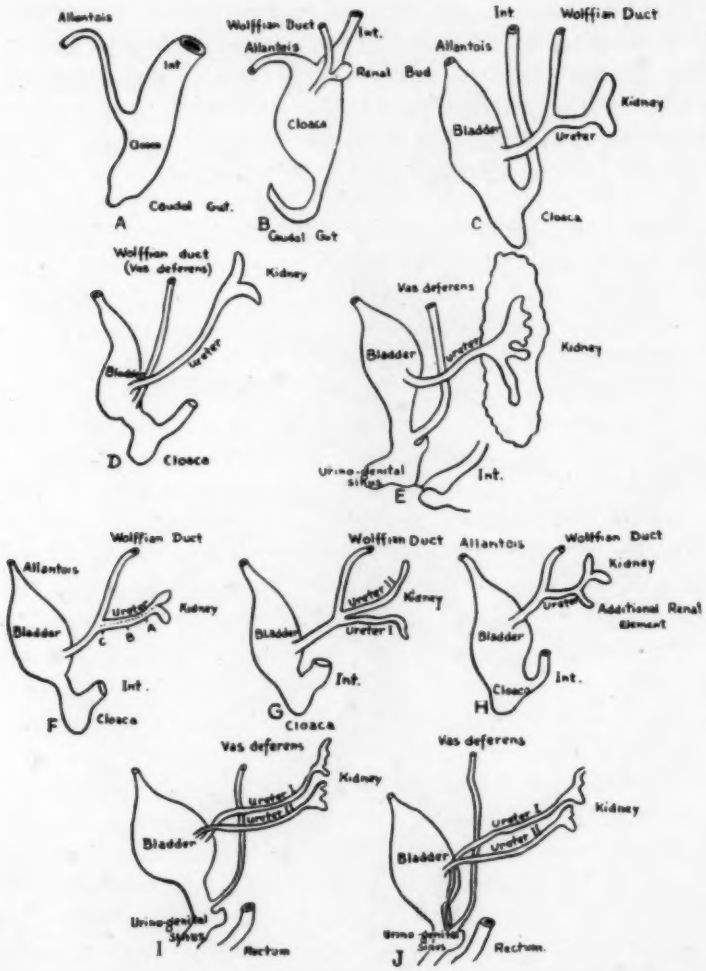

Fig. 2.—Diagram A, B, C, D, and E represent various stages in the normal development of ureter and renal pelvis from the union of primary excretory duct with cloaca to the differentiation of ureter and vas deferens, and formation of the simple pelvis with its connection with metanephros. The diagrams F, G, and H indicate schematically the process by which simple variations occur such as the incomplete bifid ureter, the accessory pelvis or calix. The diagram I and J indicate the further division whereby the complete double pelvis and ureter occur, the former showing the more usual relations of ureteral openings close together, the latter showing the descent of one ureter together with vas deferens. In either case, the lower ureter communicates with the upper pelvis and vice versa. (Diagrams adapted from Huntington.)

With the formation of the ureteric bud, the caudal portion of the nephrogenic cord becomes separated as a localized collection of cells, the metanephros, whose further development becomes intimately associated with the progressive subdividing of the ureter itself. With each budding of the ureter, a collection of metanephrogenetic cells applies itself like a cap to the ureteric bud and is carried at first dorsad, and then craniad with the growth of the ureter, until all connection with the nephrogenic cord is lost. As new orders of tubules arise and metanephrogenic tissue subdivides and increases in amount, a mass of tissue develops about the ends of branches tributary to a primary tubule, thus forming a primary renal unit, the pyramid, with its base peripheral, its apex projecting into the pelvis. Distinct tubules are then formed from the nephrogenic tissue to constitute the cortical portion of the kidney; while between the lobules, nephrogenic tissue dips downward to the pelvis forming the columns of Bertini. The collecting tubules extend in parallel columns out into the cortex, forming the cortical rays or pars radiata. In embryos of from 13 to 19 mm. length, the mass of nephrogenic tissue about each definitive tubule undergoes its specialized differentiation with the formation of a vesicle with an eccentrically placed lumen, which elongates to form at one end an S-shaped tubule uniting with a collecting tubule, while its opposite thinned-out extremity becomes the capsule of a renal corpuscle. From this S-shaped anlage, the characteristic uriniferous tubule of the human kidney develops, composed of the proximal convoluted portion, the U-shaped loop of Henle, connecting piece and distal tubule, continuous with the collecting tubule.

The migration of the kidney craniad, associated with growth of the ureter, has ceased in embryos of from 9.5 to 15 mm., in which it lies at the level of the second lumbar vertebra. Further change in its position occurs, however, conditioned by development of the collecting tubule system. The cranial and caudal poles are displaced about the renal pelvis as a fixed point so that, although during the first half of fetal life the craniocaudal diameter of the kidney corresponds to the first three lumbar vertebrae, in the second half of this period the cranial pole ascends to the level of the eleventh rib, and the caudal one descends to the upper border of the fifth lumbar vertebra. Further change in position occurs after birth. In 50 per cent. of children less than 1 year of age, Alglese found the lower pole of the kidney in the iliac fossa; in those 1 and 2 years old it was about at the iliac crest, while in children over 9 years it was always above the iliac crest. This change depends on the relatively greater growth of the posterior abdominal wall, which increases the space between the lower ribs and the iliac crests. Coïncident with growth, there occurs also a rotation of the kidney on its long axis. At first (in the 12.5 mm. embryo), the renal pelvis and collecting tubules are practically dorsad to the ureter, while in embryos of 19.5

mm. the ureteric tree occupies a lateral position. Still later, further rotation occurs, so that the adult condition is attained with the lateral border of the kidney in a place about halfway between the frontal and the sagittal position.

The arterial blood supply of the permanent kidney is a direct heritage from the mesonephros. The diagrammatic representation of the blood supply of that structure is again of aid here (Fig. 1). The vascular arrangement as described by Felix [2] is transcribed here in part.

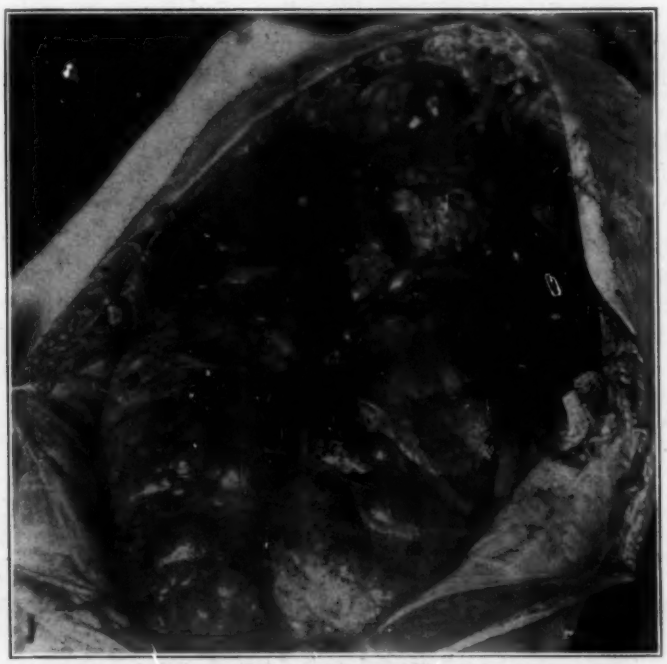

Fig. 3.—Enormous bilateral polycystic kidneys photographed in situ at necropsy. Right kidney weighed 2,340 gms., left weighed 3,180 gms. Patient died of renal insufficiency and chronic myocarditis.

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2. Keibel and Mall: Human Embryology, pp. 864-865, is transcribed here in part: The mesonephric arteries are transverse branches that arise from the aorta and run to the mesonephric fold, and their terminal branches form a network, the rete arteriosum urogenitale, lying in the angle between the reproductive gland, the mesonephros and the metanephros. In 18 mm. embryos, this network comes into connection with vessels which actually enter the renal sinus. In this way, the vessels of the metanephros become connected with the mesonephric arteries and through them with the aorta. The network makes it possible for any of the mesonephric arteries, all of which participate in its formation, to become a metanephric artery; hence, the variability in the origin of the latter, their frequent dissimilarity on the right and left side, and finally their frequent multiplicity.

TYPES OF ANOMALIES OF KIDNEY AND URETER

The types of developmental anomalies may be conveniently grouped as those of (1) form, (2) position and (3) number, concerning the kidney itself, (4) variations in the number of the ureters and (5) abnormalities in the renal vascularization.

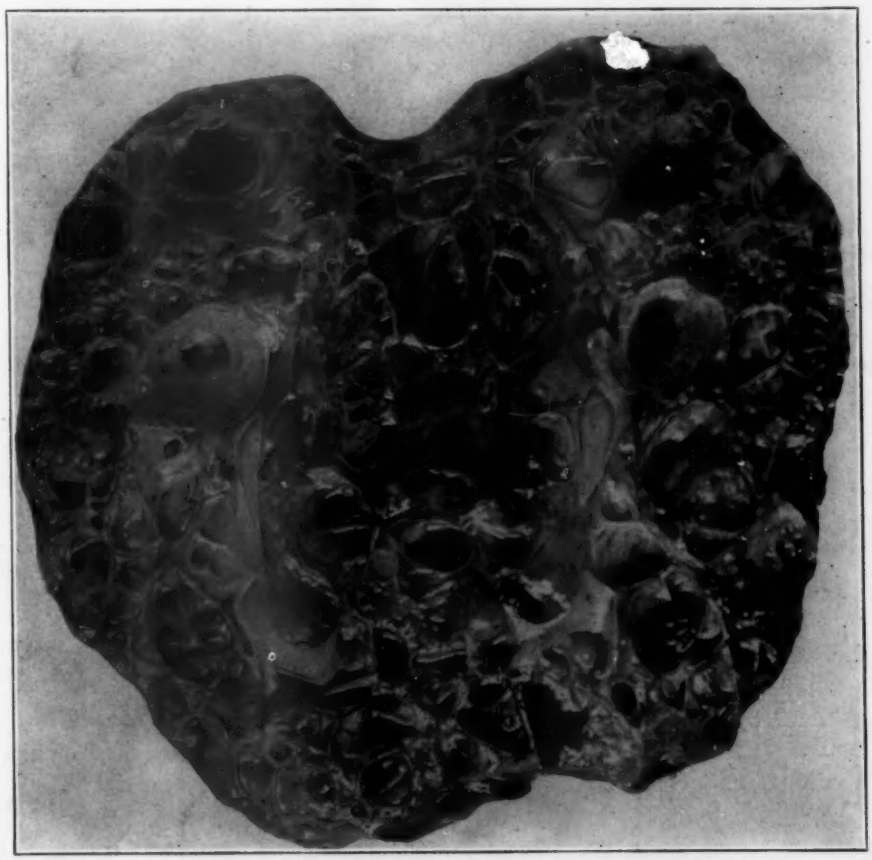

Fig. 4.—Section through left kidney shown in Figure 3.

Anomalies in Form.—The frequent variations in surface contour due to persistence of fetal lobulations have no significance when the organ is of normal size. But entire persistence of the fetal condition in one of the two kidneys sometimes occurs, the underdeveloped organ being distinctly smaller than its companion, retaining deep fetal lobulations and possessing a low functional value. Such aplasia is of clinical importance if the overdeveloped kidney on the other side becomes diseased.

An anomaly resulting in increase of size is found in the congenital polycystic kidney. This condition is ascribed by most authorities to the failure of union of that portion of the excretory apparatus arising from the wolffian duct with that coming from the nephrogenic tissue. Regarding the origin of polycystic disease of the kidney, Osler,[3] in 1915, wrote: "The origin of the condition has been much discussed, but the view put

Fig. 5.—Unilateral Fused Kidney. One half actual size. Incidental finding at necropsy in a Spaniard of 51 who had no symptoms or signs of disease of the urinary tract (Used with the permission of Drs. Blake and Winternitz of the Medical School of Yale University, New Haven).

forward by Koster is probably correct, that in an error of development there is a failure in the union of secretory and collecting tubules which

3. Osler, Sir William: Remarks on the Diagnosis of Polycystic Kidney, Internat. Clin. **1**:1-5, 1915.

develop separately." This theory has been supported by the work of Huber.[4] The inflammatory theory of origin propounded by Virchow has had no extensive acceptance. Polycystic kidney sometimes occurs in several members of the same family. It is often associated with other congenital malformations, such as harelip or cleft palate. The condition is usually bilateral. The kidney becomes enormously enlarged, at the same time retaining essentially its characteristic shape (Fig. 3). Its surface and cut section show great numbers of various sized thin-walled cysts filled with clear yellow or brownish fluid whose presence determines the increased size of the organ (Fig. 4). The kidney pelvis may or may not be deformed by the encroachment of adjacent cysts, but has no connection with them. Increased mobility of the kidney may occur, and the organ is subject to other pathologic changes. Associated changes in the liver are said to be present in 18 per cent. of the cases.

Variations in the number of the kidneys also are found with or without accompanying deviation from the normal shape. Complete absence of both kidneys is incompatible with life and is encountered only in various types of fetal monsters.

Supernumerary kidneys are rare, but the condition is to be differentiated from reduplication of the renal pelvis, either unilateral or bilateral, with double ureter, which is relatively common. In fifteen cases collected by Kretschmer [5] in 1915, the third kidney occurred on the left side in eleven instances.

Congenital absence of one kidney was found in ten of ninety-three patients dying from uremia shortly after operation on one kidney; and in eight other cases of this group, there was complete atrophy, of unknown cause (Thomson-Walker [6]). Morris [7] estimated its frequency as one in every 2,650 cases, on a basis of 15,904 postmortem examinations. In approximately 70 per cent. of cases with congenital absence of one kidney, there are associated anomalies of the genital tract, either male or female, and less frequently remote congenital defects, such as harelip, polydactylism or webbed fingers.

Extreme congenital atrophy, or unsymmetrical atrophy, of one kidney, occurs, according to Morris, in one of 2,400 cases, the left being more frequently affected. It is somewhat commoner in man than in woman. Associated with this condition is an absence of renal vessels, or they are rudimentary, and the ureter itself is absent or is represented

4. Huber: On the Development and Shape of Uriniferous Tubules of Certain of the Higher Mammals, Am. J. Anat. **4**:1-98 (Suppl.), 1904-1905.

5. Kretschmer, H. L.: Supernumerary Kidney, J. A. M. A. **65**:1447-1448 (Oct. 23) 1915.

6. Thomson-Walker: Genito-Urinary Surgery, 1914, 67-77, New York.

7. Morris, H.: Surgical Diseases of the Kidney and Ureter, Vol 2, London, 1901.

by a short stump patent for only a few centimeters. The remaining kidney is found to be enlarged in the majority of cases.

Various types of anomaly due to fusion of the renal substance are often encountered. In its minor degree, the two organs may be bound together merely by a fibrous band; while at the opposite extreme there is a complete fusion of the entire renal substance. In the so-called horseshoe kidney, the union is usually at the lower poles, or less commonly at the upper poles. Generally, both organs are nearer the spine than normal, and having failed to ascend to the adult position lie at, or just above, the promontory of the sacrum. The blood supply is frequently complex, showing a persistence of many of the original mesonephric branches. Variations in pelvis and ureter are frequent. As a rule, each kidney possesses a pelvis and ureter which passes anterior to the connecting band. The connecting band of tissue, when extensive, is sometimes found to possess a pelvis and ureter of its own. The pelvis may show irregularity of contour and size commensurate with the proportions of the kidney to which it belongs. More complete fusion types occur in the so-called sigmoid kidneys, which arise from an end to end fusion (Fig. 5), and in the shield-like kidney, representing the most complete fusion and lying usually in the midline, frequently as low as the bifurcation of the aorta.

Anomalies of position are of two types: the fixed displacements or the movable displacements. The latter group are usually acquired, except in the very rare cases of true movable kidney, in which the kidney has a true pedicle entirely invested by peritoneum. The fixed displacements were found by Morris in thirteen cases of 12,768. There is usually associated anomalous development in respect to blood supply, contour of pelvis and ureter. Genital malformations may also occur, or malpositions of other organs, as, for instance, in those cases of left pelvic kidney in which the ascending colon crosses the midline and the lower rectum is in the right side of the pelvis. The position is commonly at the aortic bifurcation over the promontory of the sacrum, or in the pelvis in the hollow of the sacrum. A rare type of fixed displacement is the so-called mural kidney, of which an example was published by Dorland[8] in 1911. In his case, found incidentally at postmortem, the organ occupied a properitoneal position in the left lower quadrant of the abdominal wall, having a vascular supply arising from the internal iliac. He found reports in the literature of two similar cases, but no additional cases have been reported since. The remaining kidney may be normal or fused with the ectopic or displaced organ.

Besides the foregoing anomalies, there is an interesting group of cases showing anomalous renal arteries, due to persisting vessels of the

8. Dorland, W. A. N.: A Consideration of Renal Anomalies, Surg., Gynec. & Obst. **13**:303-319, 1911.

mesonephric type. The knowledge of such anomalous arteries is important in operative procedures on the kidney or renal pelvis. In other instances, such anomalous arteries frequently so interfere with drainage from the kidney that a hydronephrosis develops.

Malformations of pelvis and ureter are commonly encountered. An interesting account of their origin has been given by Huntington [9] (Fig. 2). Consideration of such anomalies will not be undertaken except in relation to the renal maldevelopments with which they are associated.

REVIEW OF LITERATURE

The publications of Morris [7] and Dorland [8] afford valuable statistics on the occurrence of renal anomalies in the period previous to 1910. The monograph by Adrian and Lichtenberg [10] (1913) presents in comprehensive fashion a discussion of the subject, and offers a complete bibliography. The later monographs, in German, have been utilized with profit from the point of view of statistics; the first by Motzfeldt [11] (1914), the second by Gruber and Bing [12] (1921).

Guizetti and Pariset [13] found 4,470 anomalies in 20,000 postmortem subjects: solitary kidney in 1.95 per cent., and fusion anomalies in 1.55 per cent.; renal dystopia in 0.9 per cent. The occurrence of solitary kidney in this series is relatively higher than in any other, though the actual number of cases found, thirty-nine, corresponds closely to figures compiled from other series (Ballawitz, one in 617; Brown, three in 12,000; Cadare, one in 617; Camargo, two in 5,000). In a group of 125,644 postmortems reported from several clinics, Venzmer [14] found eighty-eight cases, or one in 1,416 cases.

Horseshoe kidney and its allied fusion forms is placed high in occurrence by most authorities. In Naumann's series, it occurs once in 598 cases; Morris found nine in 14,318; Guizetti and Pariset, eighteen in 20,000. Motzfeldt found twelve cases in 4,500 necropsies and quotes

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9. Huntington, G. S.: The Genetic Interpretation and Surgical Significance of Some Variations of the Genito-Urinary Tract, Harvey Lecture, Philadelphia, J. B. Lippincott Co., pp. 222-267, 1906-1907.

10. Adrian, C., and von Lichtenberg, A.: Die klinische Bedeutung der Missbildungen der Niere, des Nierenbeckens und des Harnleiters, Ztschr. f. urol. Chir. **1**:139, 1913.

11. Motzfeldt, K.: Angeborene Missbildungen der Nieren und Harnwege, Beitr. z. path. Anat. u. z. allg. Path. **59**:539, 1914.

12. Gruber, G. B., and Bing, L.: Ueber Nierenmangel, Nierenkleinheit, Nierenvergrösserung und Nierenvermehrung, Ztschr. f. urol. Chir. **7**:259-299 (Sept.) 1921.

13. Guizetti, P., and Pariset, F.: Beziehungen zwischen Missbildungen der Nieren und der Geschlechtsorgane, Virchows Arch. f. path. Anat. **204**:372-392, 1911.

14. Venzmer, G.: Ueber den angeborenen Mangel einer Niere, Ztschr. f. urol. Chir. **6**:162-174 (March) 1921.

other figures as follows: Boetz (1912) found an average of one in 715 of 51,504 cases; Kreft, six in 3,000; and Schul twelve in a total of 6,142.

Renal dystopia appears somewhat more frequently than is indicated in the figures given by Morris, thirteen cases of 12,768, and is a maldevelopment not uncommonly encountered clinically.

Variations in arterial supply to the kidney are extremely common, although they do not always give rise to pathologic changes. Pasteau (1909) found their occurrence in one third of a large series of cases. Papin (1910) reported their presence in sixty-four cases of a total of 320.

Variations of the ureter would appear common, several investigators finding various degrees of reduplication in about 3 per cent of cases. Motzfeldt (1914) found twenty-three cases of 4,500, and twelve in 972, when special attention was focused on these structures in postmortem examinations.

The literature of the past twelve years yields abundant examples of the various types of maldevelopments. There is an evident tendency for the maldeveloped organ to become the seat of a secondary pathologic process manifesting itself in more or less characteristic fashion. The noninflammatory types of pathologic conditions are characteristically ill-defined, and were infrequently encountered in the cases described. The actual frequency of occurrence of anomalies in the clinic may be appreciated from the statement that, between 1912 and 1917, at the Mayo Clinic, one of every twenty-six cases, in a series of 649 operations on kidney or ureter, showed a serious developmental defect.

Of the group of more than 300 cases reviewed, types of renal dystopia and fusion anomalies comprised nearly half. Dystopia occurred about twice as frequently in males as in females, and in both sexes affected the left kidney twice as commonly as the right, a finding which corresponds fairly closely to observations made in a large series of cases. Fusion anomalies were seen more commonly in males, the ratio being 3 : 2.

Only two cases of bilateral pelvic kidney were found, that of Walther [15] being unusual in that the dystopic kidneys were encroached on the bladder, causing obstruction at the vesical neck resulting in marked trabeculation and formation of a diverticulum. An interesting case of gangrene of an ectopic kidney from twisted pedicle is reported by Ransohoff.[16] This organ, in addition to its dystopic position, possessed a complete peritoneal investment. Newman's [17] case of horseshoe kidney

15. Walther, H. W. E.: Bilateral Renal Dystopia, Surg., Gynec. & Obst. **32**:82-86 (Jan.) 1921.

16. Ransohoff, J. L.: Gangrene of Ectopic Kidney from Twisted Pedicle, Surg., Gynec. & Obst. **30**:356 (April) 1920.

17. Newman, D.: Horseshoe Kidney by Union of Upper Poles, Diagnosed Prior to Operation; with Calculus in Lower Pole on Left Side, Lancet **2**:236 (Aug. 18) 1917.

with fusion of the upper poles, the kidney being in essentially a normal position, is of interest. The fusion in horseshoe form with the concavity directed anteriorly, described by Dorland, is unique. Only three well authenticated cases of supernumerary kidney were found, that of Dixon [18] being on the left side in a postmortem subject showing no other anomaly. Ten similar cases were found in the literature by Dixon, and are reviewed in his article. Routier's [19] case showed a dystopic kidney, with hydronephrosis on the right, no trace of the left kidney or ureter being found at postmortem.

Anomalies of ureter and pelvis comprise nearly 25 per cent. of the cases reviewed. Variations of the ureter occur with equal frequency on either side, but the female sex shows these conditions more frequently than the male, according to Adrian and Lichtenberg [10] and other writers. The maldevelopments were in the number of ureters or pelves, types of fusion, congenital absence, atrophy or strictures. Of the latter, Bottomley [20] reported one case and found fifty-six others in the literature up to 1915. Judd's [21] cases of single or supernumerary ureters opening extravesically (urethra or vagina) are examples of more extreme and unusual deformities. A unique case of this type is reported by Rentier as occurring in a young man of 23 dying from pulmonary and renal tuberculosis. At necropsy the right kidney showed advanced tuberculosis; the left, markedly atrophied, lay on the left common iliac artery with its single atrophic ureter emptying into the left seminal vesicle. Bifurcation of the vesical extremity of a ureter has been encountered but once (Bugbee and Losee [22]). Its embryologic development is difficult to explain. Case 14 among the series reported by Dorland must represent an embryologic crossing of the ureteral outgrowth, the right to unite with the nephrogenic mass in the left, and vice versa; for, in the adult condition in his case, the blood supply is not reported as abnormal, although the left ureter drained the right kidney, while the right ureter drained the left, both kidneys being in normal position.

In all instances of renal maldevelopment, there is easily noted an increased susceptibility of the organ to a secondary pathologic process.

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18. Dixon, F. A.: Supernumerary Kidney; Occurrence of Three Kidneys in an Adult Male Subject, J. Anat. & Physiol. **45**:117-121, 1910-1911.

19. Routier and Picart: Hydronéphrose dans un rein unique, malformations congénitales des annexes de l'utérus, Bull. et mém. Soc. de chir. de Paris n.s. **11**:209-213, 1914.

20. Bottomley, J. T.: Certain Congenital Strictures of the Ureter, Ann. Surg. **52**:597-625, 1910.

21. Judd, E. S.: Supernumerary and Single Ureters Opening Extravesically, Surg., Gynec. & Obst. **27**:13-18 (July) 1918.

22. Bugbee, H. G., and Losee, J. R.: Clinical Significance of Congenital Anomalies of the Kidney and Ureter, Surg., Gynec. & Obst. **28**:97-113 (Feb.) 1919.

Almost invariably, when only one of the two kidneys is the seat of pathologic change, it is the normally developed organ that has escaped disease. Infections, hydronephrosis and calculus formation have been commonly noted in the order named, other nephropathies being less common.

In regard to surgical treatment, one finds that, in general, it has been directed toward the superimposed pathologic condition. Rovsing [23] has recommended and performed division of otherwise "uncomplicated" horseshoe kidney for relief of a peculiar type of pain across the upper abdomen which he considered an intrinsic symptom of the fusion deformity. Herrick [24] and others have reported hemisection of a kidney with double pelvis and ureter for a localized pathologic condition. The commonly reported treatment for aberrant arteries causing hydronephrosis has been division of the vessel or nephrectomy. Less frequently, one finds reference to transplantation of the ureter. Attempts at replacement of a dystopic kidney have been uniformly unsuccessful. The surgical indications are usually obvious, once the diagnosis is established.

Fixed Displacement.—The following group of clinical cases demonstrates the symptomatology presented by patients possessing fixed displacements of the kidney and the problems encountered in diagnosis and treatment.

REPORT OF CASES

CASE 1.—*Renal dystopia and fusion. History.*—M. H., a married white woman, aged 35, entered the hospital, July 15, 1918, complaining of headache and pain in the right hypochondrium. She had been married fourteen years, and had had five normal pregnancies. Three years earlier, she had had an appendectomy and myomectomy at another hospital for symptoms similar to those now presenting. Since the birth of the last child, eighteen months previous, catamenia had recurred every two weeks, attended by undue pain and increased bleeding. For eighteen years, there had been vague attacks of epigastric pain. In the past eighteen months, there had been recurrent attacks of pain in the right hypochondrium, lasting from seven to ten days. This was always sudden in onset and cramplike, frequently radiating to the right side of the back and lasting about fifteen minutes, without chills or fever. For years, she had had nocturia (from two to three times) and, rarely, slight dysuria.

Examination.—The patient was frail and poorly nourished. There were no abnormal physical findings other than indefinite abdominal tenderness, more marked on the right side. Vaginal examination revealed nothing abnormal. Temperature, pulse, and respiration remained normal while the patient was in the hospital. The urinary examination was negative.

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23. Rovsing, T.: Beitrag zur Symptomatologie, Diagnose, und Behandlung der Hufeisenniere, Ztschr. f. Urol. **5**:586-601, 1911.

24. Herrick, F. C.: Resection of Double Kidney, Surg., Gynec. & Obst. **30**:560-563, 1920.

On cystoscopy, the bladder was found to be normal, and ureteral catheters were easily passed. Urine from each kidney was normal and free from bacteria. Pyelography revealed a small right renal pelvis lying somewhat to the right of the mid-line between transverse processes of the third and fourth lumbar vertebrae (Fig. 6). There was no shadow in the proper position of

Fig. 6.—Unilateral Fused Kidneys. Pyelogram shows displacement of left kidney, its pelvis, incompletely injected, lying between the transverse processes of the fourth and fifth lumbar vertebrae, to the right of the midline. The pelvis of the right kidney shows blunting of the minor calyces and anterior rotation.

the left kidney. The pelvis of the right kidney was somewhat irregular and showed anterior rotation. The pyelogram may be interpreted as representing most probably a unilateral fusion deformity, less probably a simple fixed dis-

placement of the left kidney. The patient declined operation and continues to suffer from the symptoms described above.

CASE 2.—*Dystopic right kidney. History.*—J. N. D., an unmarried Greek machinist, aged 35, entered the hospital, Feb. 4, 1918, complaining of abdominal pain and indigestion. The genito-urinary history was negative. He stated that for a year his general health had been below normal. He had been constipated and had lost from 15 to 20 pounds (6.8 to 9 kg.). For six months, there had been vague discomfort from fleeting pain the right lower quadrant, extending over the entire abdomen. There had been constantly severe upper abdominal distress and much gaseous eructation.

Examination.—The general physical examination revealed nothing abnormal except in the abdomen, where, in the upper quadrant, halfway between the

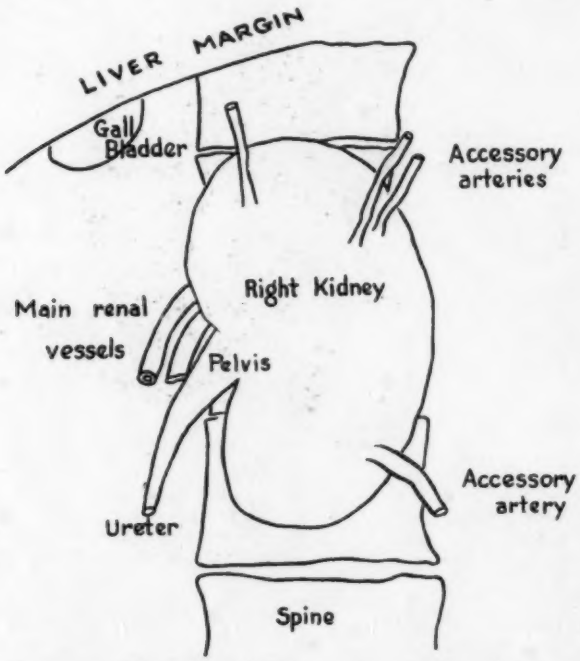

Fig. 7.—Diagram of dystopic right kidney found at operation, pelvis anterior and on lateral border of kidney which appeared grossly normal. (Case 2).

xiphoid and navel, there was a lemon-sized, smooth, nontender mass, barely movable with respiration, extending slightly beyond the edge of the rectus muscle on either side. The mass seemed deeply seated against the spine. Neither kidney was palpable. Temperature, pulse, and respiration were normal. The white blood count was 9,600. The urine examination was negative. A roentgen-ray examination of the kidney areas was reported normal. A bismuth meal revealed no abnormality of the gastro-intestinal tract. No pyelograms were made.

Operation.—An exploratory operation was performed through a high right rectus incision. The mass palpated before operation was found to be a malposed right kidney having no connection with the left kidney, which was

apparently normally placed and developed. The right kidney, definitely retroperitoneal at the level of the navel, was somewhat smaller than normal, lying fixed anterior to the spine and great vessels with its pelvis laterad. The ureter appeared normal as did the pelvis, which, however, was anterior to the renal vessels. In addition to the usual blood supply, there were two accessory arteries to the upper pole, and one to the lower pole. The central origin of these was not determined. The kidney, except for its unusual position, seemed normal (Fig. 7). A chronically inflamed appendix which was exposed and removed, was subsequently reported by the pathologist as showing "healed appendicitis."

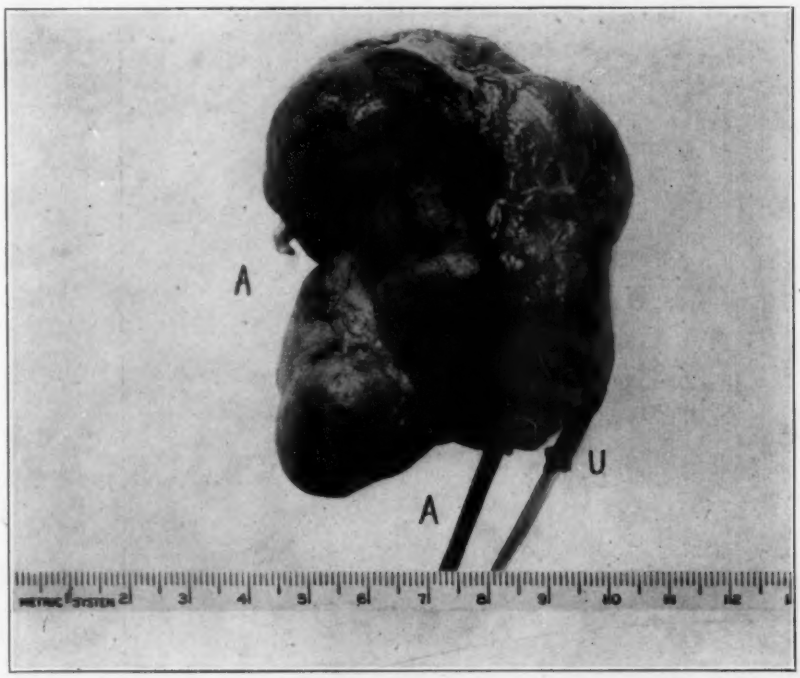

Fig. 8.—Medial view of pelvic kidney with dilated pelvis removed in Case 3. Small arteries at A and A′, glass rod in ureter (compare pyelogram in Fig. 7).

Outcome.—Convalescence was uninterrupted, and the patient was discharged sixteen days after operation. No subsequent data have been obtained, but it is not unfair to presume that his symptoms remain unaltered by the appendectomy. Unfortunately, no pyelogram was made; hence, one can only suspect the presence of intermittent blocking of drainage from this misplaced organ as the cause of the symptoms.

Case 3.—*Pelvic kidney. History.*—B. D., an American housewife, aged 26, entered the hospital in August, 1920, complaining of pain in the left lower quadrant of the abdomen. She had been married two years and eight months, and had had two miscarriages before the last pregnancy, which terminated in a normal full-term delivery eight months previous. Thereafter, there were recurrent

attacks of sharp pain in the left lower quadrant of the abdomen. The pain, which radiated down the front of the left thigh, was usually attended by vomiting, and necessitated a twenty-four hours' stay in bed. No associated urinary symptoms were present except nocturia.

Examination.—This showed that the general condition was good. There was a definitely palpable rounded, slightly movable and tender firm mass in

Fig. 9.—Renal Dystopia. The injected pelvis of the dystopic right kidney showing slight dilatation and anterior rotation (Case 4).

the left lower quadrant of the abdomen rising from the pelvis. The lower pole of this mass could be barely reached on vaginal examination. The urine was normal. Temperature, pulse, and respiration were normal, as was the leukocyte count.

Operation.—By midline suprapubic incision, a small fibroid was removed from the fundus of the uterus. Exploration then disclosed an irregular firm, slightly movable retroperitoneal mass close to the internal iliac artery on the left. The surface of this mass was definitely lobulated. Exploration of left renal fossa demonstrated the absence of the left kidney from its normal position. The right kidney was found in its normal position, considerably enlarged.

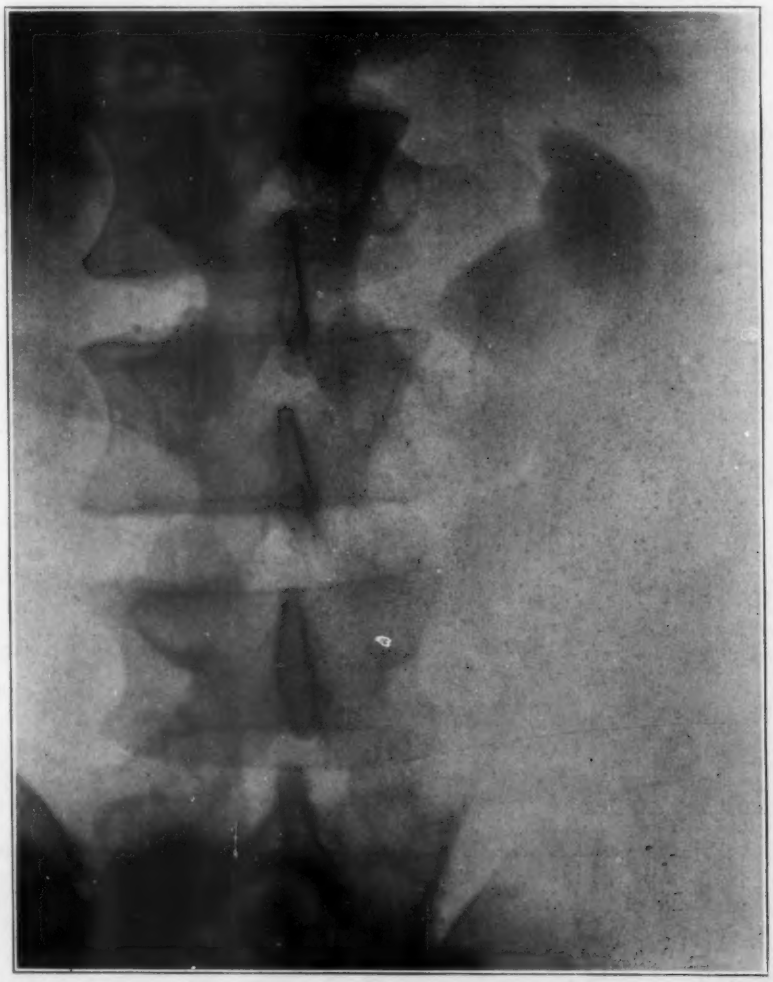

Fig. 10. Horseshoe Kidney. The pyelogram shows definite evidence of hydronephrosis but there is no suggestion here of the fusion anomaly discovered at operation. (Injected right kidney seen from behind.)

Course.—On the fourteenth day after operation, cystoscopy revealed a normal bladder, but the left ureteral orifice was displaced medially. Pyelograms showed an enlarged right kidney in normal position with normal pelvis, while

the left kidney lay in the mid sacroiliac position, its pelvis valices being markedly dilated. Divided specimens of urine were sterile, and their sediments revealed no pathologic condition. The left kidney showed practically no function. Total renal function in two hours and ten minutes was 65 per cent.

The patient was readmitted thirteen months later on account of recurrent attacks of pain as described on previous admission. In addition, there had been attacks of hematuria and frequent urination. The results of the examination were as before noted. At operation, Aug. 18, 1921, a left nephrectomy was performed through a midline suprapubic incision (Fig. 8).

Pathologist's Report.—The specimen consisted of left kidney and portion of ureter attached, which lay over the promontory of the sacrum slightly to the

Fig. 11.—Polycystic Kidney, Right. Injected pelvis of the right kidney showing retraction of the minor calyces with terminal dilatation in Case 7. Note that the outline of the extra-renal portion of the pelvis is normal and shows no dilatation.

left of the midline with the pelvis anterior. The kidney had not ascended, nor had it rotated. The specimen weighed 75 gm. and measured 7½ by 4 by 2 cm. It retained the fetal lobulations. Over the lower pole, the capsule had been stripped, leaving a deeply yellowish gray tissue over which were numerous pinhead injections. The pelvis was much dilated and measures 7 by 4 cm. on the flat side. The main vessels entered at the hilum, several smaller ones entering the pelvis and upper pole.

Outcome.—Since the operation the patient has been entirely relieved of symptoms.

CASE 4.—*Pelvic kidney (left). History.*—I. C., a Russian housewife, aged 38, entered the hospital, July 21, 1921, complaining of pain in the right lower quadrant of the abdomen, and of painful urination, beginning five years previous. The pain was intermittent, sharp and occasionally associated with nausea. Recently, the attacks had become more frequent, recurring every one to six days, and there has been more definite frequency of urination and dysuria.

Examination.—The patient was well nourished. In the lower abdomen, there was felt a slightly tender mass about 3½ by 10 cm., lying transversely, and reaching from just below the umbilicus into the right lower quadrant. Vaginal examination suggested the probable connection of the tumor mass with the right uterine adnexa. The preoperative diagnosis was ovarian cyst.

Temperature, pulse and respiration were normal. The urine, which was alkaline, showed a trace of albumin, and an occasional white blood cell. The renal function was 50 per cent.; hemoglobin, 80 per cent.; white blood count, 7,000.

Operation (July 26).—The pelvic organs were normal. The left kidney was in normal position. In the space between the promontory of the sacrum and the iliac vessels on the right a soft, irregular mass the size of a small fist was recognized as the right kidney. Incidental appendectomy was performed.

Course.—The patient was seen again, April 30, 1922, complaining of the same symptoms as before operation. Abdominal palpation demonstrated the mass described above. Cystoscopy revealed a normal bladder. Urinary examination gave normal findings. The right ureter could be catherized only 20 cm., when a clear flow of urine occurred with normal intermittent drip. The left ureter was catheterized for 30 cm., obtaining a clear flow, with peristalsis. The sediment of the divided specimens showed but very rarely a red cell or a leukocyte. A divided functional test in a ten-minute period after intravenous injection of phenolsulphonephthalein gave 12 per cent. on each side. Pyelograms (Fig. 9) showed that the right kidney pelvis lay in front of the promontory of the sacrum, rotated anteriorly, with the minor calices not demonstrated. The left kidney lay in its normal position and showed no abnormality.

In this group of four cases, each patient had undergone one unnecessary operation on account of ill-defined abdominal symptoms. In each case except the first, the all important diagnostic procedure of pyelograpy was omitted, because of the absence of pathologic urinary findings. The responsibility of a renal pathologic condition for ill defined abdominal symptoms must be constantly borne in mind.

Fusion Varieties.—The following cases are presented as illustrative of fusion anomalies of the kidney.

CASE 5.—*Horseshoe kidney. History.*—P. J. M., married, a bookkeeper, aged 32, was admitted to the hospital, July 18, 1920, complaining of pain in the right side of the abdomen. For one month before admission, there had been frequently recurring dull, lumbar backache, sometimes reaching to the mid-thoracic region. He continued to work, but found that he tired more readily than usual. On the morning of admission, he awoke with the usual backache, but was shortly seized with sharp, severe pain in the right lower quadrant of the abdomen radiating to the left side of the pelvis. He was nauseated but did not vomit. He was advised to enter a hospital because his physician feared

appendicitis. A similar attack a year before had also been diagnosed as appendicitis.

Examination.—This was negative save for occasional crackling râles at both apices posteriorly, slight resistance of the right rectus muscle in its lower portion and slight costovertebral tenderness on the right. Neither kidney was palpable. The right testicle was undescended, and lay on the pubic spine. Temperature, pulse and respiration were normal. The white blood count was from 18,000 to 8,400. The phenolsulphonephthalein test was 55 per cent. Urinary sediment showed many red blood cells and, rarely, white cells.

Cystoscopy revealed no pathologic condition save frequent, small hemorrhagic areas about and beyond the ureteral orifices. The right kidney specimen

Fig 12.—Foetal kidney, right; pyelonephritis, left (Case 8). Pyelograms show slight blunting of calyces of the left kidney, with the infantile pelvis of a foetal kidney on the right.

contained a few red blood cells and white blood cells. Cultures from the right and left sides were negative. Pyelograms showed the right kidney to be low, the pelvis opposite the third lumbar vertebra with rotation of the pelvis anteriorly. There was definite dilatation of the pelvis and minor calices (Fig. 10). The left kidney appeared to be in normal position.

Operation (July 29, by Dr. Quinby).—Exploration of the right kidney showed definite hydronephrosis. When the kidney bed was entered, the organ was found to be markedly low and to be definitely fixed in this position. Further investigation showed that the ureter and pelvis of the kidney were situated on its anterior surface, and that the lower pole of the organ became fused across

the midline to the other kidney. It was therefore immediately evident that we were dealing with a horseshoe kidney, which had not been demonstrated before operation. The ureter was freed to permit better drainage.

Outcome.—No subsequent return of symptoms was reported.

CASE 6.—*Horseshoe kidney. History.*—T. W. F., an unmarried American clerk, aged 31, had entered the hospital several times on the neurologic service for treatment of spinal sclerosis.

Examination.—On the first entry and subsequently, in addition to the other physical findings, an abdominal tumor was noted and was described as a smooth, rounded, firm mass 5 by 6 cm. in diameter, and could be palpated at the umbilical region, inclined somewhat to the left. It was pulsating and slightly movable. It seemed to be well-defined over the aorta but had no bruit or thrill. It was not tender but caused a nauseating sensation on pressure. Coughing did not produce any change in size or shape. The kidneys were not left in their normal positions. There had been frequency of urination and difficulty in starting the stream, for several years.

Cystoscopy, Jan. 8, 1920, showed marked trabeculation of the bladder and two small diverticula with ostia 1 cm. in diameter. There was hypertrophy of the trigon, but no evident obstruction at the bladder neck or in the urethra. Catheters passed 18 cm. on the right and 25 cm. on the left obtained a normal flow. Pyelograms showed the characteristic appearance of a fused kidney, probably of the sigmoid type.

Other Findings.—The fusion anomaly shown in Figure 5 was an incidental finding at postmortem examination. These kidneys found at postmortem had produced no symptoms during life. They lay at the normal kidney level and were connected by a narrow band of tissue 1.5 cm. wide and 0.5 cm. in thickness. On section, there appeared to be no dilatation of the renal pelvis, the ureters being unobstructed. The arterial supply in both these cases was multiple and complex, yet in no way interfered with drainage of the kidney.

Fusion anomalies may be quite unattended by symptoms as may the anomalies of position, but in either class of cases urinary stasis predisposes to hydronephrosis with or without infection. Accounts of partial resection of the pathologic portion of this type of fusion anomaly have been reported in the literature, but some less radical procedure must usually be undertaken. Of the various types of fusion anomalies, the horseshoe kidney offers the most favorable opportunity for surgical therapy.

Polycystic Kidney.—Polycystic disease of the kidneys, though not susceptible of cure by surgical measures, is of interest in its pathology and must be considered in differential diagnosis of certain renal tumors. Two cases are presented.

CASE 7.—*Bilateral polycystic kidneys. History.*—F. R. C., a Russian housewife, aged 43, was admitted to the hospital, Nov. 11, 1921, complaining of weakness, edema of the ankles and polyuria. There had been blurring of vision and dizziness for eight years, and nocturia (frequency, from three to five) for five years. For eight years, there had been intermittent dragging pain in the region of the right kidney. For the same period of time, there had been polyuria, nocturia and increasing dizziness.

Examination.—The patient was obese. There was moderate cardiac hypertrophy, with a blowing systolic murmur at apex. The blood pressure was: 188 systolic, 104 diastolic. Abdominal examination revealed an irregular movable elliptical firm mass in the right upper quadrant of the abdomen. It was not tender, and could be felt bimanually with a hand in the right flank. The tumor was the size of a large grapefruit and descended on inspiration. A similar though somewhat smaller mass, less freely movable, was felt in the left upper quadrant.

The urine showed a few red blood cells in the sediment and a slight trace of albumin. No casts were found. Specific gravity was from 1.007 to 1.009.

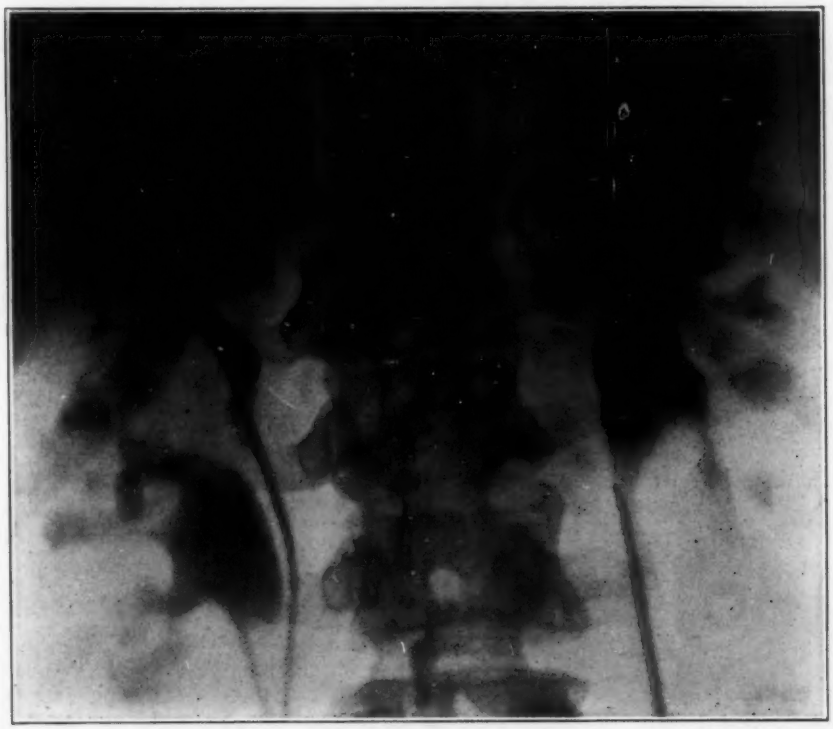

Fig. 13.—Double pelvis of right kidney, with reduplication of ureter and two ureteral orifices close together. Left kidney involved by a bleeding pyelitis.

Renal function (phenolsulphonephthalein) was 10 per cent. in two hours and ten minutes.

A pyelogram was made on the right side, and showed the outline depicted in Figure 16.

Case 8.—*Unilateral polycystic kidney. History.*—A. R., an Italian pedler, aged 49, entered the hospital, Feb. 1, 1918, complaining of pain in the right side of the abdomen. He gave a definite history of rheumatic pains in various joints during past eight years, and of palpitation with dyspnea on exertion. There was occasional edema of the ankles at night. For twelve years, attacks of pain in the right flank and abdomen radiating to the symphysis pubis had recurred.

The pain was of a dull character, though varying in severity, and at times caused the patient to double up. As a rule, the attacks lasted from five to seven weeks, during which the patient was more or less incapacitated. They recurred two or three times each year.

Examination.—The patient was obese. There was inequality of the pupils. Heart and lungs were normal. The blood pressure was 162 systolic, 100 diastolic.

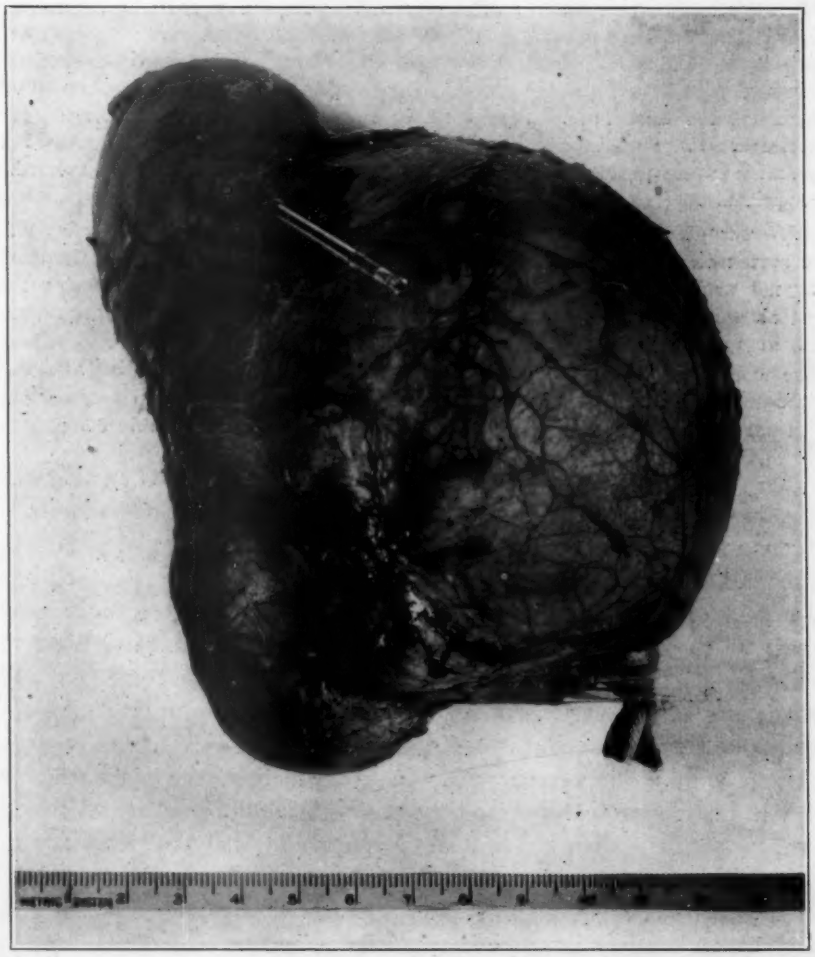

Fig. 14.—Large, hydronephrotic kidney due to anomalous renal artery crossing pelvis immediately above the ureteropelvic junction. Glass rods have been placed in the principal arteries. Specimens removed at operation (Case 12 and Fig. 14).

The urine showed red blood corpuscles, and a trace of albumin. The specific gravity was from 1.009 to 1.914. The renal function could not be estimated because of the blood. Cystoscopy showed moderate inflammation of the bladder. The catheter on the right was obstructed at 14 cm., and a grossly blood-tinged

urine appeared. On the left, the catheter passed the full distance, and the specimen showed no abnormality. The functional output on the left was 15 per cent. in thirty minutes. No pyelogram was made.

Operation.—Right nephrectomy was performed, February 8, the left kidney feeling normal to palpation although slightly hypertrophied.

Pathologic Report.—The specimen consisted of a kidney measuring 15 by 6.5 by 5 cm. and weighing 320 gm. All over the surface beneath the capsule there was a considerable number of cysts, varying much in size, from almost imperceptible ones to the largest, 1.5 cm. in diameter. The latter were bulging above the surface of the kidney. On longitudinal section, the renal parenchyma appeared similarly filled with cysts. The cysts contained a thin translucent amber-colored acid fluid. Very little of the renal substance was left. The pelvis was large and the calices extended deeply into the parenchyma. The pyramids were practically absent, and the cortical substance was hardly recognizable.

Microscopic Report.—There was a marked increase of fibrous tissue beneath the cortex and extending irregularly into the substance of the kidney. In these fibrosed areas, there were many sclerosed glomeruli. Sections through the cyst showed them to be entirely devoid of an epithelial lining. There were also areas of hemorrhage beneath the capsule, some recent, some old. There were considerable areas of renal substance composed of atypical tubules without glomeruli. The kidney contained many normal glomeruli and regions with normal tubules. The diagnosis was polycystic kidney, probably congenital.

Polycystic disease of the kidneys, when bilateral, as is usually the case, is generally easily determined. Greater difficulty in diagnosis is encountered when the process involves a single kidney giving rise to unilateral hematuria and a palpable mass in the flank. Braasch has described certain features of the injected pelvis in polycystic kidney which he regards as suggesting this condition: (1) a flattening and obliteration of one or more of the major calices; (2) retraction and broadening of the various minor calices; (3) elongation or rounding-out of the true pelvis, and (4) displacement of the pelvis from its true position within the parenchyma. But, frequently, the pyelogram is without distinctive features, and the preoperative differentiation from a renal neoplasm is then impossible. Nephrectomy may be necessary in either instance because of persistent bleeding or pain.

Only one case of congenital absence or atrophy of a kidney has been encountered in this clinic.

CASE 9.—*Pyonephrosis in single kidney. History.*—M. A. P., a single woman, aged 49, entered the hospital complaining of abdominal pain on the left side. She had enjoyed fair health until thirteen years previous to admission, when she had an attack of colicky pain in the left side of the abdomen, accompanied by transient hematuria, fever and vomiting. Since that time, at intervals of several months, similar attacks of pain recurred, usually with hematuria. Frequently, there was accompanying edema of the ankles. For two weeks preceding entrance, there had been constant dull pain in the left flank, with exacerbations of a stronger character.

Examination.—This demonstrated a large tender oval swelling occupying the left umbilical and hypochondrial region, bimanually palpable with the hand posteriorly in the left lumbar region. The lower limit was just below the umbilicus, the upper border was lost behind the left costal margin. The mass was but slightly movable.

On cystoscopy, no ureteral orifice on the right could be located, despite a clear field of vision. A catheter was passed up the left side for 20 cm., but no flow occurred. No injection of the pelvis could be made. Roentgenograms of the kidney regions demonstrated a large left kidney shadow within which there was apparently nothing abnormal.

Operation (May 15, 1919).—A much enlarged left kidney was exposed, showing a distended pelvis containing 150 c.c. of turbid foul urine. Preliminary opening of the peritoneal cavity demonstrated to the operator's satisfaction the absence of the right kidney within its proper bed, or elsewhere. A probe in the left ureter demonstrated a stricture at the ureteropelvic junction and a valvelike angulation. A plastic operation to enlarge the ureteral lumen at this point was made.

Outcome.—The patient died six weeks later of uremia.

Of interest in relation to the foregoing case is the following, in which a small fetal kidney was present on one side, its companion showing a chronic pyelonephritis.

CASE 10.—*Pyelonephritis, left, with fetal kidney on right. History.*—M. E. M., a stenographer, aged 28, entered the hospital, March 10, 1921, complaining of pain in the right upper quadrant of the abdomen. The past history was unimportant except for pneumonia following influenza two years before. Seven years before, because of pain similar to that complained of now, appendicectomy and a partial resection of the right ovary were performed at another hospital. For fourteen years, at intervals of from five to six months, the patient had experienced fleeting attacks of dull pain, occasionally quite sharp, in the right hypochondrium, without radiation. For several days following, there would be soreness in this region. For six months previous to admission, there had been soreness in the right lumbar region as well. There had never been any relation of pain to eating or exercise. There was no jaundice. There was also hourly urination by day, and nocturia twice.

Examination.—This was negative save for anemia, a right lower quadrant scar and slight tenderness in the right costovertebral angle and right hypochondrium.

Cystoscopy showed slight trigonitis. Pyelograms (Fig. 12) demonstrated the small pelvis of a fetal kidney on the right, but no abnormality of contour on the left. Ten-minute function on the right proved to be less than 0.5 per cent., and 2 per cent. on the left. The total two hour and ten minute function was 65 per cent. There was a bilateral pyelitis due to the colon bacillus.

Treatment.—Under treatment by pelvic lavage with mercurochrome-220 Soluble, 1 per cent., the infection on the right side subsided promptly without recurrence. That on the left was more stubborn.

Readmission.—The patient was discharged improved, and was readmitted two months later with an exacerbation of infection on the left. At this time, on account of a stricture of the lower portion of the left ureter and a mass posterior to the uterus, exploratory operation was performed through a midline incision. The mass found to be a cystic right ovary was resected. The

left ureter was exposed and was found dilated above its intramural portion. Consequently, the bladder was opened, the ureteral orifice dilated instrumentally and a No. 9 ureteral catheter passed up the ureter to the pelvis, the lower end being brought out through the urethra for constant drainage and pelvic lavage.

Course.—The subsequent course of this case, eventually requiring left nephrostomy for drainage of the pyonephrotic kidney, was most interesting,

Fig. 15.—Pyelogram showing bilateral hydronephroses due to anomalous renal arteries (Case 11).

but cannot be detailed here. It is to be noted, however, that the fetal kidney on the right was repeatedly demonstrated to have a functional output of less than 1 per cent. in fifteen minutes, despite the absence of infection or of demonstrable hydronephrosis, and that it was of practically no value as an excreting organ. Eventually, the patient regained complete health.

Anomalous Blood Supply.—Three clinical cases have been selected which demonstrate the interesting features associated with hydronephrosis of congenital origin dependent on anomalous arterial blood supply.

CASE 11.—*Hydronephrosis, bilateral, with anomalous artery. History.*—F. P., a male student, aged 19, entered the hospital, July 17, 1919, with the complaint of abdominal pain on the left side. The preceding history was unimportant

Fig. 16.—Unilateral hydronephrosis due to anomalous renal artery (Case 13).

except that for three and one-half years there had been recurrent attacks of acute lancinating pain localized beneath the left costal margin and in the left flank, lasting for several hours and unaccompanied by any other symptom except vomiting during the more severe paroxysms. No urinary symptoms had been noted. Occasionally, there had been similar attacks on the right side, but always of a very mild character. Repeated consultation with physicians had been unproductive of diagnosis or relief. The immediate attack preceding admission was precipitated by a fall in which the patient sustained moderate trauma to his back.

Physical Examination.—This was negative. The urine showed very rarely a pus cell. Gastro-intestinal studies made outside the hospital had been negative. On cystoscopy, the bladder and ureter were found to be normal. Catheters were passed without difficulty for 30 cm. on both sides. Divided specimens showed normal sediment from the right kidney with only rarely a pus cell from the left. Divided function, however, showed a 25 per cent. output from the right side, with no demonstrable output of the dye from the left in a fifteen-minute period. The left kidney pelvis contained 30 c.c. of 20 per cent. sodium bromid, the right 12 c.c. Pyelograms showed a bilateral hydronephrosis (Fig. 15), more marked on the left side. The constriction on either side near the ureteropelvic junction suggested the possibility of pressure by some external agency, or perhaps a true stricture.

Following cystoscopy, a characteristic attack of the old colicky pain, though more severe, was experienced, this time accompanied by vomiting, low grade fever and chills.

Operation.—A week later, the left kidney was exposed by Dr. Quinby. A marked dilatation of the pelvis was found (500 c.c. of cloudy urine evacuated by trocar), associated with a bipolar blood supply. The upper artery was very short and not readily exposed. The lower one, with accompanying veins, passed anterior to the ureter and was intimately bound to it by fibrous tissue above which level the dilatation of the pelvis occurred. A plastic repair was made by dividing the ureter at the point of constriction, closing its proximal end and transplanting it to a new position in the pelvis where dependent drainage would be possible, free from contact with the lower polar vessel.

Outcome.—Convalescence was uncomplicated, and since that time the patient has been entirely free from symptoms.

CASE 12.—*Unilateral hydronephrosis with anomalous blood supply. History.*—An unmarried woman, aged 30, a private secretary, entered the hospital, March 5, 1922, complaining of pain in the right upper quadrant of the abdomen. At the age of 14, she began to have attacks of dull discomfort in the right hypochondrium, recurring every few weeks during the next year. At 15, an operation was performed for fixation of the right kidney. This afforded no relief. The attacks continued as before, dull and indefinite in character, and attended by no other significant symptoms until ten years previously, when her right kidney was again explored. At the same time, appendicectomy was performed. Some relief was experienced until eighteen months previous, when her symptoms assumed more definite form. A dull discomfort in the hypochondrium and the flank became subacute pain after a day or two, usually relieved by local pressure, or by lying on that side in bed. These attacks recurred every ten to fourteen days. During the last two months, she had frequently noted fulness beneath the right costal margin during the attacks. No gastro-intestinal or genito-urinary symptoms had been noted.

Examination.—This was negative on admission; but, on the following day, the patient experienced the usual symptoms, and a rounded slightly tender firm mass became palpable in the right hypochondrium and flank.

The urine showed an occasional pus cell and red blood cell. The renal function was 55 per cent. in two hours and ten minutes. Cystoscopy showed a normal bladder. Ureteral catheterization obtained no flow from the right kidney. From the left, the flow was copious, its sediment normal, its function 18 per cent. in fifteen minutes. A pyelogram could not be made as the bromid solution ran back around the ureteral catheter.

Operation.—A large, hydronephrotic kidney possessing a polar blood supply was exposed, the lower artery constricting the ureter at the ureteropelvic junction, above which there was well-marked dilatation (Fig. 14). The renal pelvis was anterior, probably representing the failure of the kidney as a whole to rotate normally. Very little parenchymal tissue was present except at the two poles, and nephrectomy was performed.

Outcome.—The patient has been completely relieved.

Of striking interest in comparison with the foregoing case is that of a young girl who was in the ward at the same time.

CASE 13.—*Hydronephrosis associated with anomalous artery. History.*—A. C. G., a school-girl, aged 14, had suffered attacks of pain in the left lumbar region for three years. These attacks antedated by more than a year the onset of menstruation, which was always of normal character. Urination had been normal except for moderate diurnal frequency for several years. The characteristic attacks, lasting twenty-four hours, began with dull pain in the left flank, running forward across the abdomen beneath the left costal margin. During attacks, the patient could usually obtain relief by pressure on that side or by lying on the left side in bed. The discomfort varied greatly in severity. It was occasionally very sharp, causing nausea and vomiting, but never attended by fever, chills or urinary symptoms. She never noticed any fulness in the flank or abdomen, but always tenderneess was present during attacks. Eight months before at another hospital, the abdomen had been explored through a mid-lift, rectus incision, with negative findings. The appendix was removed.

Examination.—This was negative. Neither kidney was palpable. The urinary sediment was negative. The total renal function was 60 per cent. Cystoscopy showed a normal bladder. The ureters were catheterized without difficulty, the separate specimens showing only the occasional presence of red and white blood cells, but giving no growth on culture. No dye came from the left side in contrast to 8 per cent. from the right in ten minutes after intravenous administration. The pyelogram showed a well-marked hydronephrosis (Fig. 16).

Operation.—A polar blood supply was found with compression of the ureter, as in Case 12. The presence of much valuable kidney tissue, contraindicating nephrectomy, made possible the same type of plastic operation as that performed in Case 11, with preservation of the organ.

COMMENT

In this group of thirteen clinical cases, which do not exemplify by any means all types of renal anomalies, abdominal pain has constituted the outstanding symptom. Symptoms of urinary infection have been conspicuously absent, and this has rendered the diagnosis obscure, as indicated by the fact that previous exploratory laparotomy was performed in more than 50 per cent. of the cases. In the absence of urinary infection, there is direct contrast to the series of twenty-three cases of renal anomalies reported by Bugbee and Losee, in which but two patients failed to report significant disturbances of urination. Nevertheless, it is beyond dispute, from consideration of the literature, that the malde-

veloped kidney becomes hypersusceptible to pathologic alterations, and on this tendency depends its importance as a factor in producing disease. In the absence of a superimposed pathologic condition, the anomalous organ may be of normal functional value. When a morbid process then attacks the normally developed organ there is need of surgical treatment, the nature of which must be governed by the individual circumstances as to both the anomaly and the type of pathologic condition present.

CONCLUSIONS

1. Anomalous development of the kidney and associated structure occurs with greater frequency than is generally appreciated.

2. The maldeveloped organ of itself, though frequently giving no symptoms, has an increased tendency toward pathologic conditions.

3. The symptoms are ill-defined, and a urinary pathologic condition is frequently absent.

4. In every case with ill-defined abdominal symptoms, wherein the diagnosis remains uncertain, the patient should be subjected to cystoscopic examination with pyelography before laparotomy is performed.

5. When possible, operation should be of a conservative nature, purposing to relieve the superimposed pathologic condition and decrease the likelihood of recurrence. Nephrectomy, being a destructive operation, should be reserved for those cases not susceptible to cure by more conservative measures.

THE TREATMENT OF SPASTIC PARALYSIS *

CHARLES E. DOWMAN, M.D., AND MICHAEL HOKE, M.D.
ATLANTA

During the last three years we have studied 132 cases in which the diagnosis of infantile cerebral paralysis was made. Included in this group of cases are so-called congenital spastics, cases of spasticity resulting from arrested hydrocephalus, hemiplegias of childhood, etc. An effort has been made to determine as far as possible the etiological factors causing the condition. As a practical working basis, we have attempted a simple grouping of the clinical types encountered, independent of the etiology. A few simple considerations have been adhered to in the selection of those cases which seemed suitable for treatment, and these cases have been handled consistently, according to a preconceived plan embodying certain fundamental principles.

In order to determine the etiological factors, an effort has been made to learn as far as possible the condition of the mother's health during the pregnancy, the details of the birth, the condition of the child immediately after birth, the occurrence of convulsions, the presence or absence of a period of time in which the child seemed to be normal before the development of symptoms, the incidence of syphilis, etc. It is quite certain that there are prenatal, natal, and postnatal factors responsible for the condition. The usual prenatal causes seem to be encephalo-meningitis, intra-uterine trauma, continued poor health of the mother, microcephalus, hydrocephalus, and syphilis. Naturally, it is impossible to prove that certain cases were caused by an encephalitis occurring during the pregnancy, for example, and it is quite possible that mistakes have been made in placing cases (as far as etiology is concerned) under this head. Trauma is practically the only natal factor encountered. Such a birth trauma may be caused by the too rapid molding of the child's head, the improper delivery with forceps, prolonged labor with cerebral congestion, etc. The injudicious use of pituitary extract, with the resulting rapid expulsion of the head, may possibly be responsible for many cases of birth injury. The child's head must be molded in order to pass through the birth canal. Should this molding take place too rapidly, cerebral vessels are liable to rupture. The hemorrhages thus produced may be cortical or within the substance of the brain. This was demonstrated by Weyhe [1] who, in an analysis

* From the Scottish Rite Hospital for Crippled Children, and the Piedmont Hospital, Atlanta, Ga.; presented before the Southern Surgical Association, December, 1923.

1. Weyhe, Osler and McCrae: Modern Medicine, Ed. 3, Philadelphia and New York, Lea & Febiger, **5**:412, 1915.

of 122 cases of intra-cranial hemorrhage in infants which were examined at necropsy, found that in thirty-five instances the hemorrhages were within the brain substance, the remaining cases disclosing hemorrhages on the surface of the brain in connection with the membranes. When the injury does not cause death, there may result scleroses, cysts, brain atrophies, etc., which may give rise to the various clinical pictures of infantile cerebral paralysis. When the condition is due to some postnatal cause, there is usually the history of a normal pregnancy and birth, and a postnatal period during which the child seemed normal in all respects. Not infrequently, there is a history of a definite attack, such as may be caused by measles, influenza, scarlet-fever, or tonsillitis, followed by paralysis of varying degrees. Again, the paralysis may come after a series of convulsions with or without fever. Many of the hemiplegias of childhood seem to have begun in this way. On the other hand, there are cases in which the symptoms have developed slowly and insidiously, and may be due to some inherited weakness or defect of the motor system. Such cases, however, are difficult to classify as the result of some postnatal cause, since they probably belong to the so-called prenatal group.

With these considerations in mind we have ventured to classify the 132 cases as follows:

Etiology Undetermined		32
Probable Etiology		
1. Prenatal		36
Microcephalus	5	
Hydrocephalus	8	
Continued poor health of mother	1	
Encephalomeningitis (?)	4	
Trauma (fall of mother)	2	
Syphilis	16	
2. Natal (birth injury)		29
3. Postnatal		37
Convulsions followed by hemiplegia (underlying etiology undetermined)	16	
Febrile disturbance followed by paralysis	18	
Meningitis	3	
Total		132

In making careful neurological examinations of cases of cerebral paralysis in children it becomes evident that there are two distinct groups of cases which are easily differentiated one from the other, and a third intermediate group presenting certain characteristics of the other two groups. To the first group belong those cases which present pareses caused by lesions of the pyramidal motor system; to the second group belong those cases which present the picture of extrapyramidal tract involvement; and to the third group belong the cases presenting evidence of involvement of both pyramidal and extrapyramidal neurons.

PYRAMIDAL TRACT CASES

The picture here presented is that usually spoken of as an upper motor neuron paralysis, and presents such findings as spasticity, exaggerated tendon reflexes, patella or ankle clonus, Babinski's reflex, paresis of movements, etc. In this group may be found monoplegias, hemiplegias, paraplegias, or diplegias, according to the extent of the lesions. As certain groups of muscles are stronger and more spastic than the opposing groups, there are presented various types of deformities. In the case of the lower extremities, the adductors of the thighs being much stronger than the abductors, there is usually the characteristic crossing of the legs, or so-called scissors gait, when steps are attempted; the posterior thigh or ham-string muscles overbalance the extensor groups of the thighs, thereby causing flexion deformity of the knees; the posterior calf groups are usually more spastic or at least stronger than the anterior opposing muscles, thus causing a shortening of the heel cord and the resulting equinus position of the feet. On account of the interference with proper cerebral control, the child is unable to contract the opposing weaker groups of muscles to a sufficient degree to overcome the deformities, except perhaps in very mild cases. A more detailed consideration of the various types of deformities encountered in the lower extremities will be found below under the head of the orthopedic stage of treatment. In the upper extremities, the flexor groups of the forearm overbalance the extensor groups, and the pronators overbalance the supernators, thus giving rise to a typical deformity which is characterized principally by marked pronation of the forearm and flexion of the wrist and fingers.

EXTRAPYRAMIDAL CASES

The extrapyramidal motor system is composed of fibers conveying impulses originating in the corpus striatum (lenticular and cordate nuclei), which constitutes an important subcortical motor center, the exact function of which is not clearly understood. There are two cellular systems in the corpus striatum; namely, the large ganglion cells of the so-called pallidal system, which have long axis cylinders and are distinctly motor in function, and the small ganglion cells of the so-called neostriate system which have short axis cylinders, and whose function is probably inhibitory and coordinating. This extrapyramidal motor system seems to provide a mechanism for the performance of certain automatic acts which may still be possible when all voluntary motor power is lost (due to lesions of the pyramidal system), and likewise controls certain automatic and associated movements. In the human, the pyramidal tracts are imperfectly developed as late as the eighth month of fetal life, so that practically all of the movements of the newborn

are carried on by the extrapyramidal motor system. Lesions of this system as far as can be determined give rise, not to the typical spasticity which obtains in pyramidal tract lesions, but to a rigidity, which occurs only on excitement and on effort. In addition, there results a definite inability to perform coordinated movements, such as, for example, grasping an object and placing it where desired, proper contraction of the muscles involved in articulation, an ability to relax and to contract opposing muscles in the performance of such coordinated acts as walking, feeding one's self, etc., as well as a marked tendency to so-called athetosis. The deep reflexes under such circumstances are not necessarily increased; there is no ankle clonus and the Babinski's reflex is absent. In cases of this type, nothing could be accomplished as far as restoration of function is concerned, even though the deformities were corrected, as the nervous mechanism which has to do with the performance of coordinated movements is more or less affected.

MIXED PYRAMIDAL AND EXTRAPYRAMIDAL TRACT CASES

The cases falling in this group present findings which indicate the presence of lesions of both the pyramidal and the extrapyramidal motor tracts. In addition to the true spasticity, increased reflexes, clonus, and Babinski's reflex, there are also such findings as athetosis, inability to perform coordinated movements, dysarthria, etc.

With this grouping in mind, the 132 cases were classified as follows:

1. Pyramidal tract lesions..... 84
2. Extrapyramidal tract lesions..... 37
3. Mixed pyramidal and extrapyramidal tract lesions..... 11

In selecting cases which seem suitable for operative treatment we have discarded all cases of pure extrapyramidal tract lesions, and all cases (with one exception) of the so-called mixed pyramidal and extrapyramidal tract lesions. In the first place, these cases are not true spastics, and there are no particular groups of muscles which could be relaxed in order to obtain proper muscular balance. In the second place, should one correct through operative measures the various deformities which may be present, the child would still be unable to perform coordinated muscular movements, as the coordinating mechanism is interfered with, and, therefore, no practical results could be expected. The cases selected for treatment must be true spastics due to lesions of the pyramidal motor system. As physical training is one of the most important features of the treatment, there must, of necessity, be sufficient mentality of the individual patient to permit of cooperation as well as endeavor on the part of the patient in making the proper effort to walk or to utilize an involved upper extremity. If this mentality is not present, it is futile to attempt to give muscles the proper balance

or to correct existing deformities, as the child will be unable to accept the necessary physical training. We have selected arbitrarily a mental age of four years as a minimum degree of mental development necessary, if any favorable results are to be expected.

The method of treatment which has been used in a limited number of cases consists of three important features; namely, (1) an attempt to restore proper muscular balance by weakening through neurectomy those groups of muscles which outweigh in muscular strength the opposing groups; (2) the correction, through orthopedic procedures, of certain existing deformities which have resulted from long standing malposition of the joints, and the stabilization of the feet, which, as the result of the interference with proper cerebral control, cannot be held by the patient in the necessary position suitable for proper weight-bearing organs; (3) proper training by one thoroughly versed in this line of work, in order to teach the patient to utilize the extremities after the muscular balance has been restored and the existing deformities have been corrected.

The method of obtaining proper muscular balance is that which was first advocated by Stoffel [2] and which has been so clearly described by Gill.[3] The method consists of weakening those groups of muscles which overbalance their opponents and thus cause certain deformities as already described. This is accomplished by cutting down by means of resection the nerve supply of these overbalancing muscles. Before determining the type and degree of neurectomy, the comparative difference in strength of antagonistic muscles or groups of muscles should be carefully estimated. It is thus possible to improve in a marked degree the equalization of muscular balance between these various opposing groups.

TECHNIC OF NEURECTOMY

Arm.—When the spasticity involves an upper extremity, the usual deformity presented is flexion deformity of the elbow, a rather extreme flexion of the wrist and fingers, and a partial or complete pronation of the forearm. As a general rule, it is not necessary to weaken the nerve supply to the biceps muscle since the partial flexion of the elbow does not interfere materially with the use of the arm. The pronation of the forearm and the extreme flexion of the fingers and wrist can be overcome to a certain degree by weakening the nerve supply to the pronators and flexor group of the forearm. This is accomplished by exposing the

2. Stoffel: The Treatment of Spastic Contractures, Am. J. Orthop. Surg. **10**:611-644, 1912-1913.

3. Gill, A. B.: Stoffel's Operation for Spastic Paralysis, with Report of Thirty-Two Cases, J. Orthop. Surg. **3**:52 (Feb.) 1921.

median nerve in the bend of the elbow by a small vertical incision. The first branch leaving the median nerve in the bend of the elbow is that which supplies the superficial head of the pronator radii teres muscle. This should be divided at a point near the entrance of the nerve into the muscle. Just below the point where this branch leaves the median is a tract composed of nerves supplying the flexor carpi radialis, the deep head of the pronator radii teres, and the palmaris longus. These bundles are freed from the remainder of the median nerve and verified by means of a weak faradic current. When the pronation of the forearm and the flexion of the wrist are extreme, all these nerves should be divided. When, however, the deformity is less extreme, each one of these nerves should be partially resected to the extent of one-half to three-fourths of the nerve, according to the degree of deformity. On the dorsal and ulnar aspect of the median nerve are found those bundles which supply the flexors of the fingers. These should be separated from the main nerve, tested with the electric current, and partially resected, the degree of resection depending upon the extent of the deformity. Instead of removing a segment of the divided nerve, the central portion should be transplanted into the superficial fascia in order to misdirect the fibers when regeneration takes place, as otherwise the regenerated fibers are liable to attach themselves to the muscle and thereby restore the innervation to that degree which was present before the nerve was resected.

Lower extremity.—The deformity of the spastic lower extremity is usually that of adduction of the thigh, partial flexion of the knee, plus the deformity of the feet. The types most common are talipes equinus, talipes equinovarus, and talipes valgus. In order, therefore, to restore muscular balance, it may be necessary to resect partially or completely the anterior and posterior branches of the obturator nerve, the branches of the sciatic nerve supplying the external and internal hamstring muscles, and the branches of the internal popliteal which supply the gastrocnemius and soleus muscles.

Obturator Nerve: A small vertical incision is made just below the pubic spine and should extend downward along the tendon of the adductor longus muscle. The tendon of this muscle is retracted medially, thereby exposing the anterior branch of the obturator nerve as it courses in the intermuscular fascia. The nerve is seen to fan out into the three branches which supply the gracilis, the adductor longus, and a portion of the adductor brevis muscles respectively. These branches are completely divided and the nerve dissected up toward the obturator foramen. Should the adductor spasticity be of only moderate degree, it will not be necessary to do more than divide the anterior branch of the nerve. However, in cases of severe adductor spasm, the posterior branch of

the nerve should likewise be divided. This branch is identified by continuing the dissection and retracting medially the adductor brevis muscle behind which it passes. The nerve will then be seen lying in front of the adductor magnus muscle, where it can be easily picked up and divided as far down as the exposure permits. The posterior branch of the obturator nerve supplies the obturator externus, the adductor magnus, and at times the adductor brevis muscles. Even after dividing the anterior and the posterior branches of the obturator nerve, adduction of the thigh is still possible on account of the action of the pectineus muscle (which is that of adduction of the thigh) and which receives its innervation by means of a branch from the anterior crural nerve. In addition to the pectineus, the hamstring muscles, which are supplied by the sciatic nerve, likewise have a certain degree of adductor action. Before closing the wound, the central portions of the resected nerves should be transplanted into the superficial fascia instead of being removed.

Branches of the Sciatic Supplying the Hamstring Muscles.—When there is flexion deformity of the knee due to the posterior thigh muscles overbalancing the anterior or extensor thigh muscles, it is desirable to correct the deformity as far as possible by restoring the balance between these opposing groups, by weakening the nerve supply to the internal and external hamstring muscles. This is accomplished by exposing the upper part of the sciatic nerve through an incision which begins at the gluteal fold midway between the ischial tuberosity and the great trochanter, and which runs downward for three or four inches. The long head of the biceps muscle is retracted medially, thereby bringing into view the upper part of the sciatic nerve. On the median side of the nerve, a cord of nerve branches can be identified and separated from the main trunk. This cord is composed of three distinct nerves which can be separated from each other and identified by means of electric current. They supply the long head of the biceps, the semitendinosus and the semimembranosus muscles respectively. In case of moderate spasticity of the hamstring muscles, the branches supplying the long head of the biceps and the semimembranosus are divided. In severe cases, however, that branch which supplies the semitendinosus is partially divided, usually to the extent of one-third to one-half of the nerve. The patient will then have an intact though diminished nerve supply to the semitendinosus and a complete nerve supply to the short head of the biceps, this being sufficient to secure active flexion of the knee. The central portions of the resected nerves are likewise transplanted into the superficial fascia.

Branches of the Internal Popliteal Nerve Supplying the Gastrocnemius and Soleus Muscles.—When the condition of pes equinus is

present, it is sometimes necessary to weaken the nerve supply to the gastrocnemius and soleus muscles. This is accomplished by exposing the nerve through an incision in the midpopliteal space. The first branch which comes into view and which is superficially located is sensory in function and should not be interfered with. The motor branches supplying the outer and inner heads of the gastrocnemius, the soleus, and the plantaris are easily identified by means of the faradic current. In moderate spasticity of the posterior calf group of muscles, the branches supplying the two heads of the gastrocnemius muscle are divided. In addition to these, in more severe cases approximately one-half of the branch supplying the soleus is also divided, whereas in extreme cases this branch is entirely divided. This will still leave some action of the soleus as this muscle receives in addition a branch which leaves the main nerve on the antero-exterior aspect. As a general rule, further resection of muscular branches is unnecessary. In very extreme cases, however, it may be advisable to partially divide those branches which supply the flexor longus digitorum and the tibialis posticus. This, however, is rarely necessary. Before closing the wound, the central portions of the divided nerve should be fixed to the superficial fascia.

After the muscular balance has been more or less restored by one or more of the procedures described, there usually remain certain deformities which demand correction by various orthopedic procedures.

ORTHOPEDIC PROCEDURES

The spastic child is always delayed in learning to walk, and when it first begins to walk the lower extremity or extremities are used in an attitude which might be termed, in the beginning, a postural deformity. This attitude of the extremities develops into well established deformities. What was, in the beginning, a postural deformity has become a fixed deformity through contraction of ligaments, fascia, and tendons, and the architectural changes that have occurred in the skeleton. It is necessary to correct as far as possible these deformities. The architectural deformities are of the following types: torsion deformity of the femur, torsion deformity of the tibia, and that particular deformed architecture of the skeleton incident to the type of foot that one sees, for example, in a clubfoot or a flatfoot. Torsion deformity means a twist in the shaft of the long bone, which changes the axial relationship between the joint at the upper end of the long bone and the joint at the lower end of the long bone. Torsion deformity of the femur is manifested usually by an inward rotation of the knee. It is quite common in the hemiplegic type of spastic children. In a normal extremity, the axis of the neck of the femur makes an angle of approximately twelve degrees with the transverse diameter of the knee. The normal position of the trochanter major when the anterior surface of the knee faces forward is, of course,

well known. If torsion of the femur is present, the trochanter major occupies a position considerably behind the normal position when the anterior surface of the knee faces forward; or, in other words, if the trochanter major occupies the normal position, the rotation of the knee is markedly inward. It is worth while to correct this torsion deformity of the femur when it is unilateral; that is to say, in the hemiplegic types, for in that way the inward rotation of the lower extremity, which is a factor in the deformity, is corrected. The operative procedure by which this is done is a combination of an operation devised by the late Dr. Gwilym Davis of Philadelphia many years ago, with an osteotomy of the femur about three and one-half to four inches above the knee joint. With the patient in the prone position a longitudinal incision is made over the trochanter major; a longitudinal incision is then made through the periosteum, beginning at the upper end of the trochanter major and extending down just below this structure. The periosteum is then roughly shelled up with a chisel. The lower extremity is rotated markedly inward, which throws the trochanter forward to a normal position. The fascia lata is split longitudinally in the approach to the trochanter major. The anterior margin of this incision through the fascia lata is then picked up with clamps and held in position so that it contacts with the periosteal incision, and is stitched tightly with silk to the posterior edge of the incised periosteum so that it holds the trochanter well forward. The wound is then closed. A second longitudinal incision is made over the shaft of the femur just above the knee, and by blunt dissection the shaft of the femur is exposed. The periosteum is slit longitudinally and is completely shelled off from the bone. An osteotomy of the femur is then done. The periosteum is sutured and the wound closed. A plaster of Paris cast is applied from the toes to the costal margin with the knee rotated outward. We have found the femur-turning operation to be of value in the hemiplegic cases as above mentioned.

Torsion deformity of the tibia, which is always an outward rotation on the long axis of the tibia, is quite a factor in determining the line-up of the leg; for example, if this is a 45 degree outward torsion in the shaft of the tibia, the foot may be held in a position of 45 degrees abduction. To restore the normal mechanism of an extremity, it is necessary to set the ankle joint under the knee joint and to have the anteroposterior axis of the ankle joint approximately parallel to the anteroposterior axis of the knee joint. Torsion deformity of the tibia is corrected by an osteotomy, usually done about the middle of the tibia.

The actual correction is done in the setting in plaster.

The types of feet usually seen in spastic children are of three varieties; plain equinas deformity without any varus or valgus of the anterior part of the foot, so-called spastic flat-foot, and spastic club-foot. Pes equinus usually occurs in cases only moderately spastic, in cases where

there is quite good control of the thighs in spite of the spasticity. Spastic equinus is taken care of in one or two ways, or in both ways, either by neurectomy with release of tension of the gastrocnemius and soleus muscles, or by Achilles lengthening. At times a combination of these two methods is indicated. It does no harm to lengthen the Achilles tendon if the sheath of the tendon is not destroyed in the operation, and if the foot is set in plaster at a right angle to the leg. If the tension is cut half in two in three places, once in front, once behind, and then once in front again, stretching occurs without complete separation. We have never seen a foot injured by a lengthening of the Achilles tendon, when it is done in this way and the foot is placed in the right angle position. The difficult types of feet are the severe spastic flat-feet and club-feet. To accurately correct these two types of deformities so that the correction will hold, it is necessary to operate on them in the same way that we operate on the paralytic valgus and equinovarus feet. The motion of the ankle is that of a universal joint. The child is standing on top of a slick dome, the astragalus, and upon a chaotically controlled subastragaloid joint. It is utterly impossible for muscles responding in a chaotic way to the least mechanical stimulation from weight-bearing, to control this universal joint motion. A knee-jerk is a reflex movement induced by mechanical stimulation, namely, by tapping the patella tendon. When a child in play walks the top railing of a fence or the iron rail on a railroad track, his body and arms sway to maintain balance; his muscles are intact and act coordinatingly under brain control. The necessity for maintaining balance brings into play other movements, namely, those of the arms and the body. A spastic child standing on a slick, dome-like astragalus and on an uncertain pedestal receives many stimuli to the muscles controlling the foot, and the response to these stimuli in a chaotic way is comparable to the knee-jerk from the tapping stimulation of the patella tendon. The problem of control is too great for the brain, and therefore the chaotic effect is produced. When he attempts to walk, the feet will pull in valgus or equino varus. To overcome this situation it is necessary to remove the universal joint motion as well as to correct the architectural deformity of the foot. This is done by the stabilization operation designed in the Scottish Rite Hospital for Crippled Children, an operation for infantile paralytic flatfeet and clubfeet, and which was applied later to the spastic feet.[4]

There remains one other problem to meet: namely, the marked flexion deformity at the knee. This is a difficult problem. It is not always entirely corrected by relieving the hamstring spasticity by means

4. Hoke, M.: An Operation for Stabilizing Paralytic Feet, J. Orth. Surg. 3:494 (Oct.) 1921.

of neurectomy, for the iliotibial band and the planes of fascia on the posterior aspect of the thigh which are in connection with it are thickened and shortened; the posterior ligament of the knee-joint is likewise thickened and shortened, and the architectural changes in the contour of the lower end of the femur and upper end of the tibia interfere with the restoration of complete extension of the leg, in some instances. The method of correcting much of the flexion deformity at the knee is as follows: a plaster of Paris cast is applied to the lower extremity from the toes to the groin; a section is taken out of the cast at the knee joint; there is incorporated in the cast at the knee a mechanical instrument with worm gears which work with a pinion and key, and each day the gears are moved with the key in such a way as to extend the leg a bit.[5] Often one can obtain in this way complete extension of a flexed knee, provided there are no architectural changes in the knee joint. In other instances, complete extension of the leg at the knee can not be obtained, and to reduce the flexion deformity sufficiently to make the extremity a weight-bearing one, it is necessary to perform what we call a "back tibia" operation. It has been recognized that recurvatum of the knee joint is a good position for the extremity when there is marked but not total paralysis of the quadriceps extensor muscle. With recurvatum of the knee a child can walk without a brace. The method of producing recurvatum has been to do a supracondyloid osteotomy of the femur and set the extremity with the knee in recurvatum. We substitute an osteotomy of the tibia for an osteotomy of the femur. The osteotomy of the tibia is performed just below the tibial tuberosity, and, in setting the extremity, the following principle is followed: from the outer surface of the extremity, extend a plumb line from the center of the knee down below the foot. In the setting in plaster, the foot is so placed forward that the external malleolus is just in front of this plumb line. While the cases have not been numerous in which we have had to do this operation, there are particular cases in which one can not adequately correct the flexion of the knee unless such a recurvatum of the tibia is produced. There is, of course, a slight bowing backward of the tibia below the knee. It is absolutely necessary in order to produce a fairly good looking extremity (when viewed laterally) not to do a high tibia osteotomy for the production of a back tibia, until you have reduced the flexion deformity to approximately fifteen degrees.

In many instances the postoperative care amounts to no more than the institution of muscle training. In other instances, leg braces are necessary in addition to the physical training.

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5. This very useful device was designed by Mr. C. H. Martin, the brace maker for the Scottish Rite Hospital for Crippled Children, Atlanta, Ga.

PHYSICAL TRAINING

When the plaster casts are removed the child receives very light massage for the weaker muscles, a few general exercises, and a few special exercises. These exercises are very simple, and are given each day in the same way, as any slight variation confuses the child of a spastic type. Before placing the child on its feet, shoes are fitted. If the child has never learned to walk, he is first started by being taught to stand between parallel bars. When he is able to stand without assistance, he is taught to take steps. When he is able to walk between the bars easily and has established the habit of doing so, crutches are given him. At first, he is only taught to stand with crutches. When he is able to stand with crutches without assistance, he is taught to take steps. By this time, he has established a sense of balance and soon learns to walk with the aid of crutches, thereby establishing this habit. Every new step is very difficult for the spastic child, for being retarded both mentally and physically, he prefers to go the way of least resistance and makes very little voluntary effort to walk or to get about in any way. In dealing with such children, one should be firm but gentle, keeping the instructions simple, but making them do their exercises and take the steps necessary for daily progress. When they have learned to walk, they are very glad to be able to get about and are sufficiently active. They are then in a position to gain both mentally and physically, because their activities and interests are greater.[6]

REPORT OF CASES

Since January, 1922, eighteen patients have been treated. All of these are still under observation and, in some, the treatment has not yet been completed. With the exception of one case, belonging to the so-called mixed type, all the patients treated presented pyramidal tract lesions. The fact that only seventeen of the eighty-four cases of pyramidal tract lesions have been treated, would seem to indicate that a very small percentage of these cases are suitable for treatment. There are several factors, however, which are responsible for such a small percentage in our own series of cases. For example, in quite a number of the patients examined, the mental age necessary for the beginning of treatment had not been attained. Such patients are being kept under observation, and many will doubtless attain, at some time in the future, the necessary minimum age. Other patients are still under the physical age of four years. Again, there are many patients for whom treatment has been advised, but for some reason or other the children have not yet been admitted to the hospital. As previously mentioned, all cases belonging to the extrapyramidal tract class and all except one of the so-called mixed type have been thrown into the discard as absolutely unsuitable for treatment.

Case 1.—G. L. D., a boy, aged 10, was admitted to the hospital Dec. 30, 1921. There was no history obtainable in the case, except that the patient had never

6. The physical training of the cases reported in this paper has been conducted by Miss Elizabeth Dunnican and Miss Lois Wright, Atlanta, Ga.

walked; for several years he had been able to pull himself along on his abdomen by means of his arms, propelling himself, as it were, by means of his legs, which were held tightly together.

Examination.—Both legs were extremely spastic. The child was unable to stand alone, and when prone was unable to separate his legs on account of the extreme adductor spasticity. The posterior calf groups of muscles were not particularly spastic; the feet, however, were held in an equino valgus position. The knee-jerks are highly exaggerated, and there is a bilateral Babinski's reflex. There is also a marked bilateral ankle and patella clonus. The arms seem to be normal, and show splendid muscular development.

Operations.—The following were performed:

Jan. 27, 1922: Bilateral resection of the anterior and posterior branches of the obturator nerves.

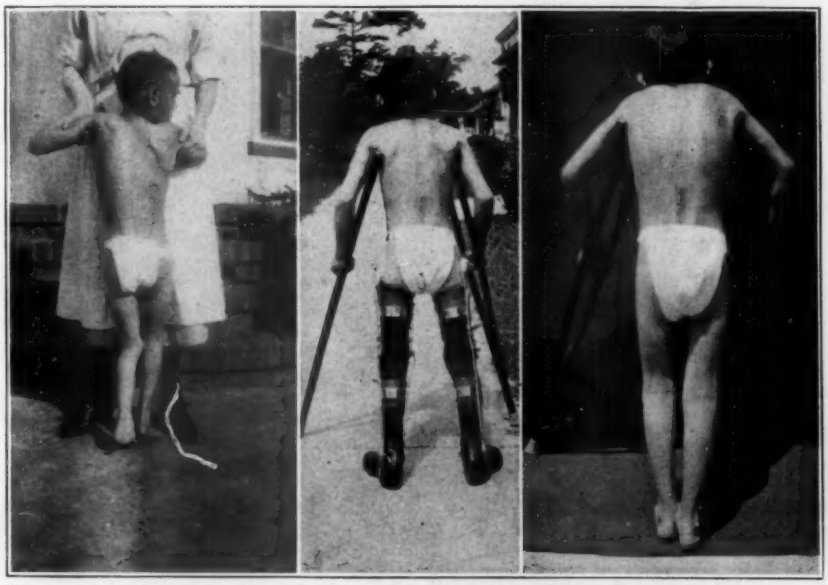

Fig. 1 (Case 1).—Posterior view showing the correction of the adductor spasticity of the thighs, and the improved position of the feet.

Feb. 17, 1922: Bilateral partial resection of the branches of the sciatic nerve supplying the hamstring muscles.

March 6: Left high tibial osteotomy plus left ankle stabilization.

March 23: Right high tibial osteotomy plus right ankle stablization.

May 1: When the plaster casts were removed, the feet were found to be stable and the ankle motion good, with no element of deformity of the feet. The flexion deformity of the knees seemed to have been corrected, as there was sufficient backward bowing of the tibia to compensate for the flexion. The child responded splendidly to physical training, walking fairly well with crutches. The legs were still somewhat spastic, but he was able to separate his thighs and could advance his legs one in front of the other in making

steps. Braces were applied, to be worn for a month and then every other day for another month, after the use of which he should be able to dispense with them entirely.

June 28, 1923: Every effort was made to have this child return for observation, but since there were no answers to the letters, the final result cannot be reported.

CASE 2.—L. M., a girl, aged 15, was admitted to the hospital, March 21, 1922. There was a history of an inability to walk properly all the patient's life. When she was about two years of age, she had been able to walk with a stick. At that time, there was a marked tendency for the legs to cross when she attempted to take steps. At about 8 years of age, it was necessary for the patient to begin to use crutches in order to get around. The family history was negative. The patient was a full term child, and the birth was normal. There was no history of convulsions, and the patient seemed to be perfectly healthy up to the age of 6 months. At that time, she was dropped by one of her sisters, and soon after this it was noticed that she could not use her legs as do most babies of this age. She is somewhat retarded mentally, although she has been as high as the fourth grade in school.

Examination.—The patient was able to walk with the aid of crutches, but in doing so there was an exaggerated scissors gait, and the process of taking steps is definitely interfered with on account of the difficulty of advancing one leg in front of the other, due to the marked spasticity of the adductor group of muscles of the thighs. There was a bilateral ankle and patella clonus, and a positive bilateral Babinski's reflex. The knee-jerks were highly exaggerated. There was a partial, though not complete, loss of control of the bladder sphincter. There was likewise a fair degree of flexion deformity of the knees.

Operations.—The following were performed:

March 31, 1922: Bilateral neurectomy of the anterior branch and partial neurectomy of the posterior branch of the obturator nerves.

April 21: Bilateral partial neurectomy of the branches of the sciatic nerve supplying the hamstring muscles.

May 19: The patient walked with the aid of crutches and had lost the scissors gait entirely. The knees were still slightly flexed. The result so far was very satisfactory, and with continued physical training patient should eventually be able to dispense with her crutches.

CASE 3.—L. B., a girl, aged 6, was admitted to the hospital, April 4, 1922. She had never been able to walk without assistance. When supported, she was able to take steps, although there was a definite scissors gait, and she walked on the balls of her feet, with a definite flexion of the knees. It was only during the last year that she had been able to walk even with assistance. The patient's birth was spontaneous although premature (7 months). The mother thinks the labor was difficult. After birth, the child slept almost constantly for two months. There was no history of convulsions. At the age of seven months, there was a febrile attack diagnosed as infantile paralysis by the attending physician. The family history was negative.

Examination.—The patient was able to stand with support. When she did so, however, there was a definite equinus position of the feet, the knees were held close together, and there was a distinct flexion deformity of these joints. In attempting to walk the gait was distinctly scissors in character. The legs were definitely spastic, the particular groups of muscles which were especially involved

being the hamstring and adductor groups of the thighs. The knee-jerks were highly exaggerated, and there was a bilateral Babinski's reflex. When the patient stood, the knees were flexed at an angle of 45 degrees, and the feet were in a clubfoot position:

Operations.—The following were performed:

April 10, 1922: Bilateral neurectomy of the anterior branches of the obutrator nerves.

April 10, 1922: Bilateral neurectomy of the anterior branches of the obturator nerves.

April 21: Bilateral neurectomy of the branches of the sciatic nerve supplying the biceps muscle.

Fig. 2 (Case 3).—Lateral view showing correction of the flexion deformity of knees and deformities of the feet.

May 18: Bilateral ankle stabilization.

By July 18, this child had been receiving physical training and had been watched continually in order to determine whether or not an osteotomy of the tibiae for the production of "back tibia" and the correction of inward torsion would be necessary. When she stood, both knees were flexed, the right more then the left. When she attempted to walk, the right toe struck against the hollow of the left foot, on account of the right tibia being bowed and inwardly rotated.

July 20: Osteotomy of the tibiae to correct inward torsion and to produce "back tibiae."

The casts were removed on August 24, 1922. September 12, the patient could extend the legs at the knee voluntarily. The tibiae were bowed backward, and the patient could abduct the legs a little. Physical training was instituted. Patient could walk on crutches to a certain extent. When she did so, however, there was a tendency for the left leg to be rotated inward, therefore it seemed necessary to have braces applied.

October 3: The patient was discharged wearing leg braces. These braces were applied for the purpose of paralleling the lower extremities and of preventing a recurrence of the flexion deformity. The problem is now one of home management. She should wear her brace regularly and dispense with the crutches as soon as possible. It was quite possible for her to be able to do this in six months. The feet were stable and the lower extremities were well lined up.

Case 4.—L. R., a girl, aged 9, was first examined on April 18, 1922. The patient was said to have been perfectly normal until 18 months of age when she had a febrile attack. After this illness, the child seemed to be generally paralyzed. After that, she has been unable to walk, unable to talk plainly, and seemed to have great difficulty in using her arms. The family history was negative. The patient was a full term child, the birth normal, and there was nothing following the birth to indicate that the child was other than a normal baby.

Examination.—When the patient spoke she did so in a slow, drawling, rather indistinct manner accompanied by marked facial grimaces. There was a definite bilateral optic atrophy. When the child was instructed to grasp an object with either hand, the hands and arms went through a series of athetoid-like movecents before the object was grasped. She was able to feed herself, but with great difficulty on account of the strange movements of the arms. The intelligence seemed to be very good and the patient cooperated in the examination. She was unable to stand without support. When she stood with support there was a flexion deformity at the knees, the feet were outwardly rotated, and she stood on the balls of her feet. The knees were held close together. When she attempted steps there was a distinct scissors gait, and the toes were dragged on the ground to such an extent that the dorsal surface of the toes came in contact with the ground. Both legs were distinctly spastic. The knee-jerks were highly exaggerated; there was a marked bilateral ankle clonus, and a bilateral Babinski's reflex.

Comment.—This was a marked case of spasticity with particular involvement of the legs. The athetoid movements of the arms and the dysarthria indicated that there was also definite involvement of the extrapyramidal motor system. The case, therefore, belongs to the so-called mixed group, as both the pyramidal and extrapyramidal tracts are involved. On account of the spastic condition of the legs outweighing the evidence of extrapyramidal tract involvement, it is felt that the patient should be given the benefit of an attempt to improve her condition by properly devised neurectomies, orthopedic corrective measures, and physical training.

October 17, 1922: The patient admitted to the hospital.

Operations.—The following were performed:

October 25: Bilateral neurectomy of the anterior and posterior branches of the obturator nerves.

November 9: Bilateral typical flatfoot type of stabilization, plus Achilles lengthening, followed by weekly wedging of the plaster in an effort to correct the flexion of the knees.

Jan. 31, 1923: Bilateral resection of one branch of the sciatic supplying the internal hamstring muscle.

February 22: Bilateral high tibial osteotomy with greenstick type of production of "back tibia."

April 20: The patient had had physical training for several weeks. She now attempted to walk on crutches with assistance.

May 1: As the result of the "back tibia" operation, the child could bear her weight and was able to walk the length of the room with no tendency of the knees to flex. Her legs were straight and her improvement was marked.

May 15: The patient was walking with crutches without assistance. Both feet were stable. They looked normal with and without shoes. She had free

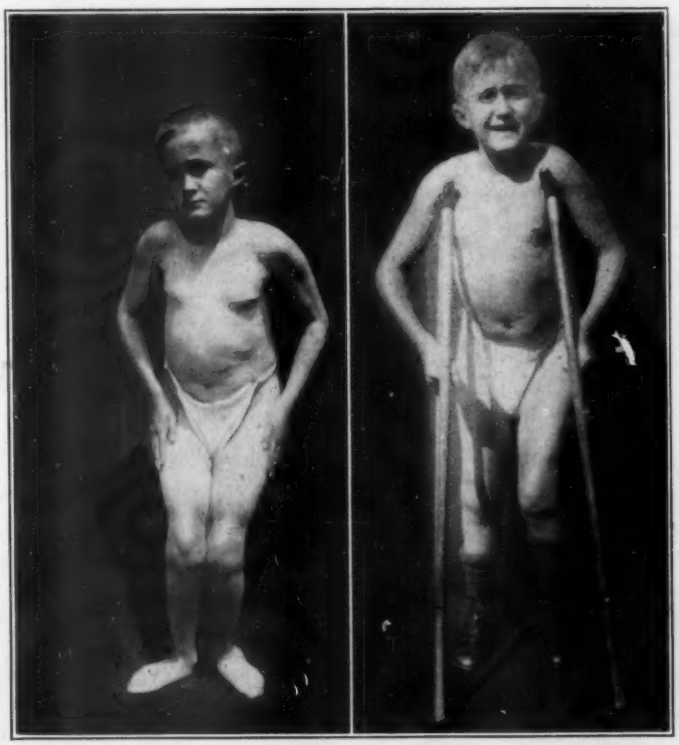

Fig. 3 (Case 5).—Anterior view showing correction of the adductor spasticity of the thighs and the deformity of the feet.

ankle motion and there was no knee flexion. When we considered that this child, on admission, could not even stand and was absolutely helpless, we felt that the result to date had been most satisfactory. She could walk several hundred yards with the aid of crutches and could do many things for herself that she could not do before admission to the hospital.

Case 5.—L. C., a boy, aged 11, was admitted to the hospital, May 16, 1922. The father noticed when the child was one year of age that the head was abnormally large. This enlargement increased very rapidly until the patient was two years of age, remaining the same size ever since. The patient had

never been able to walk and had not been able to support himself on his feet even when steadied by someone. The arms have not been affected. At the age of five, he began to have generalized convulsions. From this time up to three years ago, he had about twenty-five such attacks. He has had no convulsions since. The mother had three other pregnancies, all of which were full term, but the children were born dead. The patient was a full term child, and the birth was normal. He had never attended school and had the mentality of a child about five years of age.

Examination.—The head was distinctly hydrocephalic in size and shape, having a circumference of twenty-six and three-quarter inches (65 cm.). When the patient was held up on his feet, the knees were in a distinct position of flexion deformity and were closely approximated. The feet were everted and in marked valgus position. There was a distinct outward torsion of the tibiae. The knee-jerks were highly exaggerated; there was a bilateral ankle clonus and a bilateral Babinski's reflex. The feet were rather flail-like. There was a marked tremor of both hands, and the hand grip was weak on both sides. There was a moderate degree of bilateral optic atrophy. The Wassermann reaction was negative on blood and spinal fluid.

Comment.—This was a case of arrested hydrocephalus, with resulting spasticity of the legs.

Operations.—The following were performed:

May 24, 1922: Bilateral resection of the anterior branch of the obturator nerve.

June 8: Bilateral high tibial osteotomy for production of "back tibia."

July 6: Bilateral ankle stabilization.

August 17: The feet were nicely corrected. The knee flexion had also been corrected by a back bowing of the tibia, so that the heels were now in line with the shaft of the femur. The patient was given shoes, and physical training was commenced.

August 29: The patient could walk between parallel bars. He could also balance himself and stand with crutches, and with assistance could walk with crutches. There was no element of scissors gait. When sitting, he could flex and extend the knees voluntarily.

September 19: There was no deformity of the feet. They looked natural with shoes on. When the child stood up, someone had to help him out of the chair and support him until his crutches were given to him. He stood up with a good deal of tremor of the legs and arms. When he was once up he could walk the length of the ward with the aid of crutches. When he stood, the legs were flexed 30 degrees at the knees, and the hips were flexed 30 degrees as he leaned forward on his crutches. There was no tendency for the knees to strike together, and the patient placed his feet very well on the floor when he walked. As he had never walked before it is felt that he had gained a great deal. He now makes baskets and uses his hands very well.

November 7: The patient came back for observation walking erect with crutches. He held the spine, the hips, and the knees almost in a normal position. The feet were stable and appeared normal. The result so far was very satisfactory.

November 6, 1923: The patient returned to the clinic walking on his crutches. He was able to balance himself without support and could take a few steps without crutches. With the aid of crutches he walked fairly well. In taking steps, he lifted the feet up from the underlying surface. There was a

tendency, however, for the knees to knock together. This was particularly marked on the left side. The feet had a tendency to assume a flatfoot position on walking. The feet were stable at the site of the subastragaloid arthrodesis and astragaloid-scaphoid arthrodesis. The articulation between the internal cuneiform and scaphoid bones was abnormally mobile, and permitted extreme abduction and pronation of the forefoot. It was, therefore, felt that this child could be improved still more by further operative procedures.

Operations.—The following were performed:

November 9, 1923: Bilateral resection of the branches of the sciatic nerve supplying the long head of the biceps and the semitendinosus muscles. Bilateral fusion of the internal cuneiform joint and scaphoid articulation. After removing the cartilaginous surface of this articulation, bone shaving grafts were cut and left between the raw surfaces of the bone. The feet were then put in plaster in a corrected position.

November 21: Bilateral resection of the posterior branches of the obturator nerve.

December 1: The patient was still in plaster casts. It was confidently expected, however, that those subsequent operative procedures would materially better the patient's ability to walk. Even without these operations, however, the result had been satisfactory, considering the rather hopeless condition which the patient presented when first admitted to the hospital.

Case 6.—H. B., a girl, aged 5, was admitted to the hospital, June 20, 1922. This patient had first been examined on April 5, 1920, at 2½ years of age. At this time, there was an inability to walk and a lack of proper use of the left arm and hand. The family history was negative. The patient was a full term child, and the birth had been normal. There was no history of convulsions or infectious diseases. The patient had learned to talk at the age of one year, but had never learned to walk. There was a spasticity of the legs and a slight spasticity of the left arm and hand. The knee-jerks were exaggerated and there was a bilateral Babinski's reflex. The case was considered one of spastic paraplegia, but on account of the age of the patient the parents were instructed to bring her back when she was 4 or 5 years of age.

Examination.—At the time of admission to the hospital, the child was unable to stand alone. The feet were in a marked valgus position. She was rather refractory and did not cooperate in the examination. The knee-jerks were highly exaggerated. There was a bilateral ankle clonus and a bilateral Babinski's reflex. The spasticity was particularly marked in the adductor groups of the thighs and the posterior calf groups of muscles. When the child was stood upon her feet, the ankles rolled either inwardly or outwardly, and the feet were so unstable that they did not bear her weight. After admission, child was given intensive physical training for a period of time. She was then discharged and readmitted on September 5, 1922.

Operations.—The following was performed:

Sept. 7, 1922: Flatfoot type of stabilization on the right side. Clubfoot type of stabilization on the left side. There was a question as to whether the Achilles tendon should be lengthened. This was not done.

September 30: The patient was discharged with casts.

October 12: The casts were removed. The left foot was satisfactory. The subastragaloid joint was stable. On the right side, the subastragaloid joint was stable, but the foot was in a bad valgus position. The peronei were very short and spastic.

October 24: The patient walked between parallel bars. She was discharged, and the parents were instructed to continue the physical training.

Feb. 13, 1923: The patient was readmitted to the hospital. She had not been walking in parallel bars at home, and the condition was no better than when she left the hospital. The right gastrocnemius muscle was very spastic, causing a short heel cord. This had produced a recurrence of an extreme type of flatfoot. She had free motion between the head of the astragalus and the scaphoid, and there was evidently firm bony fixation between the os calcis and astragalus. It was felt that if the gastrocnemius muscle was relaxed by means of neurectomy and the foot held with a "swung in" shoe, the foot would assume a normal position. The left foot was in very good condition, but there was considerable spasticity of the posterior calf group of muscles.

Operation.—The following was performed:

Feb. 21, 1923: Bilateral partial neurectomy of branches of the internal popliteal nerve supplying the gastrocnemius and soleus muscles.

April 17: The child was walking for the first time in her life. She walked with crutches, placing her feet forward eight inches (20 cm.) at a time. She was discharged.

May 22: The patient was readmitted to the hospital. She came into the clinic walking with her crutches, and her gait had greatly improved since the last observation. The left leg and foot were in excellent position. The right foot presented an extreme type of flatfoot deformity.

Operation.—The following was performed:

Nov. 16, 1923: Fusion of the right scaphoid and internal cuneiform articulation, followed by the application of a plaster cast to be removed in six weeks.

CASE 7.—C. C., a boy, aged 9, was first seen, June 20, 1922. No history could be obtained except that the child had had difficulty in walking all of his life.

Examination.—This disclosed a very awkward gait. Although the patient was able to walk without support he dragged the balls of his feet on the ground in a typical spastic manner. When he walked, the knees were held in a slightly flexed position, and there was a tendency for the knees to knock together when steps were taken, thereby interfering materially with the progress of the advancing leg. Both legs were quite spastic, the knee-jerks highly exaggerated right and left, and there was a bilateral Babinski's reflex. There was a recurvatum of the right knee when the patient was standing, with a torsion of the right tibia of four to five degrees. The Wassermann reaction was negative.

Comment.—This was a case of typical spasticity of the lower extremities of a moderate degree.

December 12: The patient was admitted to the hospital. During the first few weeks following admission, he was given physical training.

Operation.—The following was performed:

Jan. 19, 1923: Bilateral resection of the anterior branch of the obturator nerve.

January 30: When the boy walked, his feet were quite straight; they remained at right angles to the legs when he lifted them in the air, and they did not turn into varus. He still walked with the knees slightly flexed, but when he stood, he could straighten them. There was no tendency for the knees to knock together when steps were taken. Further operative measures did not seem to be indicated as necessary at this time.

August 14: The patient was brought to the clinic for observation. There was no tendency to adductor spasm, and the knees did not knock together when he advanced his steps. There was still a definite spasticity of the posterior thigh groups, although the patient was able to extend the knees fairly well, and could lift his feet from the ground in taking steps. It was felt, therefore, that for the time being there was no indication of the necessity for further operative measures. The patient was instructed to return in one year for further observation.

CASE 8.—D. C., a girl, aged 3, was first examined, June 20, 1922. There was a history of an inability to walk, an inability to sit alone, a crossing of the eyes, and a large head—all of these conditions being present since birth. The

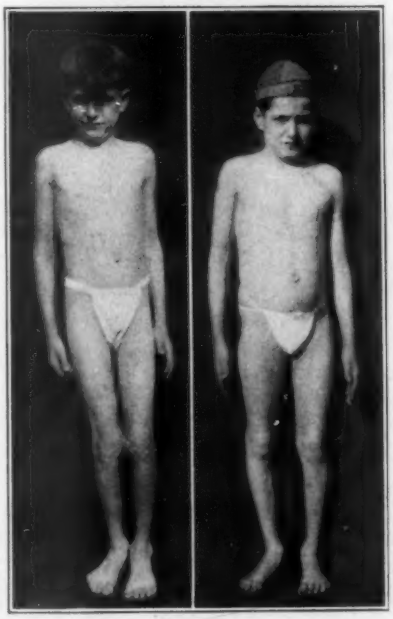

Fig. 4 (Case 7).—Anterior view showing correction of adductor spasticity of thighs. (Left hand view is before operation.)

family history was negative except for tuberculosis in the father. The patient was a full term child, and the birth had been normal. There had been no convulsions. The mother's health during the pregnancy had been considered good. At the time of birth, it was noticed that the child's head was abnormally large.

Examination.—The patient's head was distinctly hydrocephalic in both shape and size. The circumference of the head was twenty-one and three-fourths inches (55 cm.). The intelligence was good, although the child was distinctly spoiled by the mother. She was able to hold up her head, and would support herself on her legs when assisted. When she attempted to take steps, there was a marked scissors gait, and the child stood on the balls of the feet. She had better use of the left arm than of the right arm and hand, this extremity being somewhat

spastic. The legs showed a definite degree of spasticity; the knee-jerks were highly exaggerated, and there was a bilateral Babinski's reflex.

Comment.—This was a case of spasticity, which probably resulted from an arrested hydrocephalus. The lesion was distinctly pyramidal motor in type. The child was put on the waiting list until she attained the age of four years.

May 29, 1923: The patient was admitted to the hospital. The findings were practically the same as those noted at the first examination.

Operations.—The following were performed:

June 1, 1923: Bilateral resection of the anterior branches of the obturator nerve.

June 30: Bilateral partial neurectomy of the branches of the internal popliteal nerve supplying the gastrocnemius and soleus muscles.

July 12: Bilateral stabilization of the feet, with the application of plaster from the toes to the groin.

June 23: The patient was discharged in the plaster cast.

August 21: The patient was readmitted to the hospital.

August 23: As the result of the stabilization operation, both feet were in normal position. There was a dorsal flexion of fifteen degrees beyond the right angle, and there was free ankle motion. There was very good relaxation of the adductor groups of the thighs and the posterior calf groups. The posterior thigh group was somewhat more spastic on the left side than on the right. Further neurectomies, however, were postponed until the child had received physical training.

September 10: The patient walked between parallel bars. There had been some improvement in the ability of the child to stand and walk in this way. The mother was instructed to continue the physical training.

November 6: There was splendid relaxation of the adductor groups of the thighs and of the posterior calf groups of muscles. There was only moderate flexion deformity of the knee. The patient, however, made no effort to walk, and there was no parental control. As far as could be determined, there was no reason why the patient should not walk if she made the effort. It was felt that the operations in this case were undertaken too early since the child, as yet, did not appreciate the importance of cooperation in the necessary physical training.

Case 9.—H. E., a boy, aged 7, was admitted to the hospital on August 8, 1922. The patient had never been able to walk. His birth had been premature (six and one-half months), and he weighed at birth 2½ pounds (1.11 kg.). Labor was induced on account of the poor health of the mother, who had severe albuminuria and albuminuric retinitis. There was one stillborn child of the parents. The family history was otherwise negative. The patient began to talk at 18 months of age; he had had several severe febrile illnesses, particularly scarlet fever and influenza.

Examination.—There was a moderate degree of spasticity of the left arm. The use of the arm, however, though not as good as normal, was fair. The patient was able to sit up, although the back was bent forward. He was able to stand only when supported. When he did so there was marked flexion deformity of the knees, and the feet were in a marked flatfoot position. When steps were attempted, there was a marked scissors gait and the patient had difficulty in advancing his legs on this account. There was an unsustained ankle clonus on both sides, the knee-jerks were highly exaggerated, and there was a bilateral Babinski's reflex. The intelligence of the child was very good.

Operations.—The following were performed.

August 16, 1922: Bilateral neurectomy of the anterior branches of the obturator nerve. A section of the nerves was removed instead of the central portion being transplanted into the superficial fascia.

August 30: Partial neurectomy of branches of the sciatic nerve supplying the hamstring muscles.

September 14: Bilateral flatfoot type of stabilization.

December 12: Since October 26, when the casts were removed, the patient had been given physical training. He was now able to walk with crutches the length of the ward.

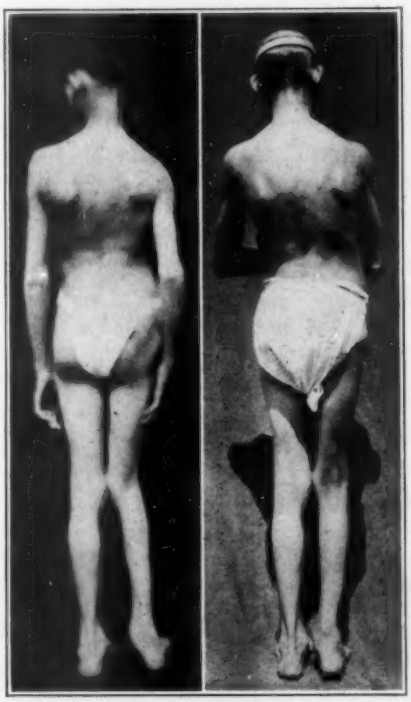

Fig. 5 (Case 9).—Posterior view showing improvement of right leg and foot.

December 23: The patient was discharged, walking with crutches, and the parents instructed to continue the training.

May 8, 1923: The patient came in for observation. He was able to walk with crutches, but had never been able to walk without this aid. The gait was still of a moderate scissors type, and it was felt that the adductor muscles of the thighs must be further relaxed by resection of the posterior branches of the obturator nerves. There was a permanent knee flexion of about 20 degrees, which would have to be corrected eventually by tibial osteotomy. It was felt that the child should be given further training before these operations were performed.

November 13: The patient was readmitted to the hospital. He was able to walk across the room on crutches. The parents thought that his improvement had been very definite. In the act of stepping forward, the knees had a tendency to knock together, and the feet to turn inward. This was particularly true of the right foot. When the child was prone, there was a very distinct adductor spasticity, particularly on the right side. The hamstring groups were likewise very spastic. The feet were in very good position, particularly the left foot. There was, however, considerable spasticity of the posterior calf groups of muscles. It was felt that this child was still too spastic to obtain the maximum amount of use of the legs.

Operation.—The following was performed:

November 21, 1923: Bilateral resection of anterior and posterior branches of the obturator nerve. Although a section had been taken out of the anterior branch at the operation Aug. 16, 1922, this nerve had completely regenerated and, when stimulated electrically, there was a marked contraction of the adductor longus, adductor brevis and the gracilis muscles. This observation emphasized the necessity of simply dividing the nerves and transplanting the central portions into the superficial fascia, in order to misdirect the fibers when regeneration should take place.

The patient was in the hospital when this report was made, and will be retained until further resection of the nerves supplying the hamstring muscles and the posterior calf groups of muscles has been performed.

Case 10.—C. A., a boy, aged 6 years, was admitted to the hospital, Aug. 22 1922. There was a history of an abnormally large head, first noticed by the parents when the child was 3 months of age. The head continued to increase rapidly in size until the patient was 6 months of age. Since that time, the head had not grown larger. At 6 months of age, the circumference of the head was twenty-four (61 cm.) inches. There had been an inability to walk alone. The family history was negative. The patient was a full term child, and the birth was normal. It was noticed that the child's head was abnormally large at the time of birth.

Examination.—The circumference of the head was twenty-five inches (64 cm.). The fontanelles were closed. The head was distinctly hydrocephalic in shape and size. There was a moderate degree of bilateral optic atrophy. The patient was very intelligent. There was no spasticity of the arms. He walked with support. In doing so, however, the knees were partially flexed and knocked together; the heels did not come in contact with the underlying surface, and the child found it difficult to clear the toes from the ground in advancing steps. There was a bilateral sustained ankle clonus and a bilateral Babinski's reflex.

Comment.—This case, in which there was very good mentality, was one of arrested hydrocephalus, with a residual spastic paraplegia.

Operations.—The following were performed:

Aug. 28, 1922: Bilateral neurectomy of the anterior branches of the obturator nerves.

September 15: Bilateral partial neurectomy of the branches of the sciatic nerve supplying the hamstring muscles of the thighs.

October 3: It was difficult to describe the patient's gait, except to say that he walked twenty feet by himself with someone by his side to keep him from falling. His gait was very unsteady. There was, however, no tendency to scissors gait, although when he walked the legs were flexed slightly at the knees and his feet were in the position of spastic flatfeet. When he lifted the

knees, he scraped the dorsum of his toes on the floor. Considerable physical training would have to be given before the necessity of further operations was indicated.

May 29, 1923: The patient was readmitted to the hospital. When he stood, the heels were about one inch (2.5 cm.) above the underlying surface, and the knees were partially flexed. The patient was able to stand alone, and to walk with the knees slightly flexed. There was no tendency to scissors gait; there was a slight tibia torsion and Achilles tendon contracture producing a clubfoot type of deformity. This condition was present on both sides.

Operation.—The following was performed:

June 1, 1923: Bilateral partial neurectomy of the branches of the popliteal nerve supplying the gastrocnemius and soleus muscles.

June 19: The child was walking with crutches. His feet were set squarely on the ground. The muscles of the legs were relaxed. The result, so far, appeared to be satisfactory. The patient was to return in three months, when it would be determined whether or not orthopedic operative procedures should be made.

CASE 11.—J. N. K., a boy, aged 17 years, was first examined, January 16, 1923. When the patient was 2 years of age, there was a sudden paralysis of the whole right side, including the face, arm and leg. He remained completely paralyzed on this side during the following eight hours, after which there was a slight return of movements. This had gradually improved, although there still remained a definite weakness on the right side. When he was eight years of age, there were performed some kinds of operations on his right foot, which from the history, were performed in order to correct a spastic clubfoot. The mother had one miscarriage following a four months' pregnancy, and had given birth to one premature child. The family history was otherwise negative. The patient was a full term child, and the birth was apparently normal. He had been perfectly healthy until he was two years of age, when the present illness began. He learned to talk at about the usual age, and there had never been any symptoms of aphasia.

Examination.—There was a slight sluggishness of the movements of the right side of the face. The right arm was moderately spastic, although he could write fairly well with the right hand. The movements of this extremity, however, were somewhat awkward. The right leg was very spastic. The hamstring group, the adductor group of the thigh, and the posterior calf group of muscles were all very spastic on the right side. There was a marked tendency for the foot to be held in pes equinus. The right knee-jerk was highly exaggerated. When the patient walked, the right leg was thrown inward with marked adduction and inward rotation of the thigh. The right hip was held higher than the left, and the patient walked on the ball of the right foot. In taking steps, there seemed to be very little movement of the right hip joint, although, when the patient was prone, the passive movements of the hip joint were fairly good. It was impossible, however, either actively or passively, to rotate externally the right thigh. The leg was distinctly shorter and smaller than the left.

Comment.—This was a case of old right hemiplegia with marked disability of the right leg, due probably to a lesion in the region of the left internal capsule involving the pyramidal fibers.

Operations.—The following were performed:

April 18, 1923: Neurectomy of the anterior and posterior branches of the obturator nerve on the right side, and partial neurectomy of the branches of the internal popliteal supplying the right gastrocnemius and soleus muscles.

May 3: Right foot stabilization by bone graft shavings taken from the tibia and placed in the subastragaloid fossa between the head of the astragalus and scaphoid.

June 26: As the result of neurectomy and foot stabilization, the boy's walking was very much improved. The foot was stable and looked normal with or without shoe. He had free ankle motion, with a dorsal motion beyond the right angle. There was no tendency to the equinus position. The adduction spasticity had likewise been relieved.

Case 12.—H. C., a boy, aged 14 years, was admitted to the hospital, January 23, 1923. There was a history of difficulty in walking all his life. The patient had never been able to walk until he was eight years of age; after that, since which time he walked on the toes with a high stepping gait, and seemed to have considerable difficulty in balancing himself. The family history was negative. The patient was a full term child, and the birth was normal, as far as known. During the first week after birth, the child cried constantly and seemed to have difficulty in breathing. There was no history of convulsions. The patient was in the fifth grade at school.

Examination.—When the patient walked he had considerable difficulty in balancing himself. He walked on the balls of the feet, and threw his legs out in a high stepping gait. In order to propel himself forward, he threw one leg in front of the other by hyperextending the knees. The gait resembled that of a "high school horse." There was no tendency to scissors gait. The legs were distinctly spastic, particularly the posterior calf group of muscles. There was a bilateral ankle clonus, highly exaggerated knee-jerks, and a bilateral Babinski's reflex. There was a moderate degree of spasticity of the arms, though not enough to interfere with the use of these extremities.

Operation.—The following was performed:

Jan. 31, 1923: Bilateral partial neurectomy of branches of the internal popliteal nerve supplying the gastrocnemius and soleus muscles.

February 20: The patient's gait had been wonderfully improved. He no longer had the high stepping gait, and the feet were placed flat on the underlying surface when he took steps. There was a tendency, however, for his knees to knock together in walking, due to a certain amount of spasticity of the adductor groups of the thighs.

Operation.—The following was performed:

Feb. 21, 1923: Bilateral neurectomy of the anterior branches of the obturator nerves.

March 25: The patient was discharged. The deformity had been corrected, and the gait was greatly improved.

October 16: The patient was readmitted to the hospital. Although his gait had been considerably improved, there was still a certain amount of unsteadiness. When he walked, the bottom of the heel touched the ground frequently, though not all the time. Before the neurectomies, the bottoms of the heels never touched the ground. It is felt that the lack of stability of the feet constituted the main factor of disability.

Operation.—The following was performed:

Nov. 1, 1923: Bilateral ankle stabilization plus Achilles lengthening, with the application of a plaster cast with the feet set in 105 degrees of dorsal flexion. The patient was still in a plaster cast at the time of the report. It was felt, however, that his gait would be considerably improved by this last operation.

CASE 13.—I. L. F., a girl, aged 9 years, was admitted to the hospital, Feb. 27, 1923, on account of an inability to properly use the left arm and the left leg. This was first noticed when the patient was a very small infant, and it was thought by her aunt, with whom she lives, that the child was probably born with this disability. She was a full term child and the birth had been normal. There were no convulsions immediately after, or since, birth. There was no history of any serious illnesses. The father died of pneumonia and the mother died of the hemorrhagic type of malaria. There were four other children of parents who are living and well. One of these, however, had some form of mild paralysis of the foot when quite young, which was overcome by proper exercises. The mother miscarried once, the pregnancy being of four months' duration.

Examination.—There was a peculiar high stepping gait with the left leg, and an awkwardness of the movements of the left arm and hand. There was a definite degree of spasticity of the left arm; a marked spasticity of the posterior calf group of muscles of the left leg, causing the foot to be held in a marked pes equinus position; a fair degree of spasticity of the adductor group of muscles of the left thigh, and a moderate degree of spasticity of the ham-string groups of the left thigh, particularly of the internal hamstring muscles. The knee-jerks and the deep arm reflexes were highly exaggerated on the left side. There was present a left Babinski's reflex.

Comment.—This was a case of left hemiplegia due probably to some lesion in the region of the right internal capsule. The exact etiology could not be determined.

Operation.—The following was performed:

March 7, 1923: Partial neurectomy of the branches of the internal popliteal nerve supplying the left gastrocnemius and soleus muscles.

March 27: As the result of the neurectomy, which was followed by some physical training, much of the child's spasticity had been relieved. The foot set squarely on the ground, and there was no tendency to equinus. As the foot was fairly stable, the necessity of a stabilization operation at that time did not seem to be indicated.

July 31.—The patient returned for observation. Her gait had been greatly improved. She now placed the left foot flat on the underlying surface, whereas before the operation she walked on the toes of this foot. The left arm and hand were in the same condition as on the previous examination. The child picked up objects with considerable awkwardness and difficulty; there did not seem, however, to be enough deformity of the arm to warrant operations.

CASE 14.—A. B., a boy, aged 14 years, was admitted to the hospital, March 27, 1923. The patient was brought by a public health nurse who could give only a few facts in regard to the history. The patient was a nine months pregnancy, but nothing was known in regard to the labor. At the age of two days, he had generalized convulsions. These had continued at frequent intervals ever since. Although the convulsive movements were general there seemed to be particular involvement of the right side. A partial paralysis of the right arm and right

leg had been present all of the patient's life. His health had always been fairly good; he attended school and was in the sixth grade, having learned to write with the left hand on account of the disability of the right arm.

Examination.—There was a marked nystagmus when the patient looked to the extreme right and to the extreme left. There was a distinct sluggishness in the movements of the right side of the face. The right arm and right leg were definitely spastic, and were shorter and smaller than the left arm and leg. When the patient gripped with the right hand, the wrist was flexed to an acute angle. The right arm is held in a semiflexed position at the elbow and there was a marked pronation of the forearm. When the patient stood the right foot was in an extreme pes equinus position. There was a distinct limp with the right leg when he walked; the heel was fully 10 cm. above the underlying surface and turned inward. The knee was also turned slightly inward, and there was a tilting of the right side of the pelvis, when the patient took steps with the right leg. He was able to extend and flex the right knee to a normal extent. There was no movement possible in the foot except slight flexion of the toes. Marked spasticity of the adductor group of the right thigh was present. The right knee-jerk was highly exaggerated, and there was a right Babinski's reflex.

Comment.—This was a case of old hemiplegia of the right side, due probably to a lesion in the region of the left internal capsule, with involvement of the pyramidal tracts.

Operations.—The following were performed:

March 30, 1923: Neurectomy of the anterior branch of the right obturator nerve and partial neurectomy of the branches of the internal popliteal nerve supplying the gastrocnemius and the soleus muscle on the right side.

April 12: Stabilization of the right ankle plus Achilles lengthening.

June 12: Right leg: the alinement was good; the foot looked normal with and without a shoe, and the patient had free ankle motion. The active dorsal flexion was possible beyond the right angle. The ankle was stable. The patient was not nearly as spastic as he had been on admission, and the gait was greatly improved.

CASE 15.—F. L., a boy, aged 12 years, was admitted to the hospital, April 24, 1923. When 9½ years of age, the patient had a severe febrile attack accompanied by extreme lethargy and lasting three or four weeks. After this illness, there was a marked disability of the left arm and left leg. The patient walked with a distinct limp and was unable to get the left heel flat against the underlying surface. He had been distinctly retarded mentally, and has developed in addition a tendency to kleptomania. The family history was negative. The patient was a full term child and the birth had been normal. There had been no serious illness and no disabilities until the onset of the present illness.

Examination.—When the patient walked there was a distinct limp with the left leg; the left foot was in a condition of pes equinus, and patient walked on the ball of the foot. The left leg had a tendency to turn inward, and the knee knocked against the right knee when he advanced his left leg in front of the right. The left leg was somewhat shorter and much smaller than the right. There was a general spasticity of the muscles of the left leg. The left knee-jerk was highly exaggerated, and there was a left Babinski's reflex. The adductor group of the left thigh and the left posterior calf group of muscles were particularly spastic. The left arm was also shorter and smaller than the right, and there was a distinct spasticity of this extremity. There was fairly good use of the arm and hand, however, in spite of this condition.

Comment.—This was a case of old left hemiplegia, the condition having developed after an illness which was probably some form of encephalitis. The lesion was of the pyramidal motor system type.

Operation.—The following was performed:

May 1, 1923: Partial resection of the branches of the internal popliteal nerve supplying the left gastrocnemius and soleus muscles, and complete resection of the anterior branch of the left obturator nerve.

May 17: The patient walked with a very slight limp. The foot set squarely on the ground, and there was no tendency to equinus in the left foot. The parents were instructed to train the child to use the left hand and arm in the daily activities of life.

November 6: When the patient stood, he did so with both feet flat on the underlying surface. When he walked, there was a slight limp with the left leg, which impressed one as being due to the slight shortening of the leg rather than to a spasticity. He did not walk on the toes of the left foot as before the operation. Neither did the left knee knock against the right when he advanced his steps. There was no spasticity of the left thigh adductor group of muscles. There was an active dorsal flexion of the left foot beyond the right angle position. In spite of the spasticity of the left arm, the patient had fairly good use of this extremity.

CASE 16.—D. M., a girl, aged 3½ years, was admitted to the hospital, May 9, 1923. There was a history of abnormal gait, first noticed by the parents when the patient began to walk at one and one-half years of age. At that time, when she attempted to walk, the heels did not touch the underlying surface. During the last six months, the toes had been turned inward, and the knees knocked together, interfering with each other when steps were taken. With the exception of one sister who had a slight paresis of the right side following convulsions during the first three or four days after birth, the family history was negative. The child had been born prematurely (eight months). The delivery had been normal, mother being in labor, however, only 55 minutes. There were no convulsions and the child seemed to be perfectly healthy until 9 months of age, when she had a rather severe febrile attack.

Examination.—When the patient stood supported, the feet were turned inward, and the heels were elevated above the underlying surface. When she attempted to take steps, there was a marked tendency to scissors gait. The legs were distinctly spastic, the spasticity being particularly noticeable in the posterior calf group of muscles, right and left, as well as in the adductor groups of both thighs. There was, in addition, a moderate degree of spasticity of the posterior thigh groups of muscles, a left clonus and a bilateral Babinski's reflex. The knee-jerks were highly exaggerated right and left.

Operations.—The following were performed:

May 11, 1923: Bilateral partial neurectomy of the branches of the internal popliteal nerve supplying the gastrocnemius and soleus muscles.

May 17: Bilateral ankle stabilization.

May 23: Bilateral neurectomy of the anterior branch of the obturator nerve.

After the plaster casts were removed, the patient was given physical training for several months.

August 20: There was no spasticity whatsoever of the adductor groups of the thighs. The feet were in excellent position, and child could walk very satisfactorily. The parents were instructed to continue the training, and to bring the child back in one year for observation.

CASE 17.—R. F., a girl, aged 12 years, was admitted to the hospital, September 11, 1923. The patient was able to walk with support. When she did so, she walked on her toes, and her gait was very unstable. There was an inability to use the right arm properly and an inability to talk, the patient being able to say only a few simple words. The mother had miscarried twice, the pregnancies being of two months' duration. This child had been prematurely born (seven months), the labor having lasted four days. The mother's health during the pregnancy had been very poor. The patient had been a delicate child practically all her life. Even when she was very young it was noticed that she had a peculiar form of twitching of the muscles, but no frank convulsions. At eight months of age, she could not sit alone. When she was three years of age, there had been some form of light spasms, not accompanied by loss of consciousness, which occurred about once a month. During these attacks, the right hand jerked more than the left. The atacks had continued ever since.

Examination.—Although the patient was unable to talk, she seemed to have fair intelligence, and cooperated well in the examination. There was a mild bilateral optic atrophy, and patient could not move her eyes to the left beyond the midline, although she was able to look well to the right. The right arm and hand were much smaller than the left. There was a marked flexion of the right elbow, extreme pronation of the forearm and extreme flexion of the wrist and fingers, due to a definite spasticity. The patient had practically no use of this extremity. When she was supported on her feet and attempted to take steps, the heels were about one inch (2.5 cm.) above the underlying surface, the feet were markedly everted and the legs very spastic. The spasticity was particularly marked in the adductor groups and hamstring groups of the thighs, and the posterior calf groups of the legs. There was a bilateral ankle clonus, highly exaggerated knee-jerks and a bilateral Babinski's reflex.

Operations.—The following were performed:

September 21, 1923: Bilateral resection of the anterior branch of the obturator nerves.

September 26: Bilateral partial neurectomy of the branches of the internal popliteal supplying the gastrocnemius and soleus muscles.

October 16: As the result of the neurectomies, the legs were not so spastic as on admission. With assistance, the patient could move both extremities in an attempt to walk. The knees, however, were flexed 30 degrees. When she stood, both feet were in extreme valgus position.

Operation.—The following was performed:

Nov. 1, 1923: Bilateral flatfoot type of stabilization. As there was still marked tarsal and metatarsal valgus and an extreme degree of motion in the scaphoid cuneiform joints, it would be necessary, at a future operation, to fuse the scaphoid cuneiform joints, as well as to perform osteotomies of the first metatarsal joints; these procedures would be followed by proper fixation of the feet in plaster. Following these procedures, the cast should be wedged at the knees for correction of the flexion, as this was about 30 degrees of fixed flexion.

CASE 18.—J. L. N., a boy, aged 5 years, was admitted to the hospital, September 18, 1923. There was a history of the patient's having been unable to walk or talk; these symptoms had been present all his life. One brother had died at the age of 8 months of meningitis. Two paternal aunts had died in an insane asylum. The family history was otherwise negative. The patient was a full term child, and the birth had been normal. The mother's health during the pregnancy had been good. At the age of 3 weeks the child had had a severe attack of influenza. He had recovered from this, however, and had seemed

normal until he was 10 months of age, when he had had an attack of bronchopneumonia. The parents thought that his disabilities dated from this latter illness.

Examination.—The child was unable to talk, and there seemed to be a definite impairment of hearing. He seemed of good intelligence and cooperated well in the examination. He had good use of both arms and hands, but was unable to stand without support. When he was held up on his feet, he was able to take steps, after a fashion. There was a marked tendency to scissors gait and a marked equinus position of the feet; likewise a fairly marked flexion deformity of the knees was present. The knee-jerks were highly exaggerated, right and left. There was a bilateral ankle clonus and a bilateral Babinski's reflex. The groups of muscles which seemed to be particularly spastic were the adductors of the thighs, the posterior calf groups, and the hamstring muscles of the thighs.

Operations.—The following were performed:

Sept. 26, 1923: Bilateral partial neurectomy of branches of the internal popliteal supplying the gastrocnemius and soleus muscles.

October 26: Bilateral resection of the branches of the sciatic nerve supplying the long head of the biceps and the semimembranosus muscles, and partial neurectomy of the branch supplying the semitendinosus muscle.

November 9: Bilateral resection of the anterior branch of the obturator nerves.

November 26: As a result of the neurectomies, the equinus position of the foot had been relieved, and both heels set squarely on the ground. The adductor spasticity of the thighs had, likewise, been relieved, and there was only a very slight flexion deformity of the knees. The child was responding splendidly to physical training.

CONCLUSIONS

1. In the study of 132 cases of infantile cerebral paralysis, it seems that there were prenatal, natal, and postnatal factors which may have caused the condition.

2. The clinical pictures presented in cases of infantile cerebral paralysis are of three types; namely, that caused by pyramidal tract lesions, that caused by extrapyramidal tract lesions, and a mixed type in which both the pyramidal and extrapyramidal tracts are involved.

3. In selecting cases for operative treatment, only those cases which belong to the pyramidal tract group are suitable subjects.

4. The cases selected for treatment should have a minimum intellectual age of four years.

5. There are three important features in the treatment of the spastic child, namely, the relaxation of certain groups of muscles by means of neurectomy, the correction of fixed deformities and unstable feet by means of orthopedic operations, and the use of physical training in teaching the child to walk after these operative measures have been employed.

6. Eighteen cases have been treated in this manner and the results obtained seem to justify the opinion that this combination of methods of treatment is essential if the spastic child be given the maximum amount of useful function.

BLADDER SENSIBILITY *

THOMAS D. MOORE, M.D.
Fellow in Urology, Mayo Clinic
ROCHESTER, MINN.

It is not unusual to observe patients with unmistakable evidence of a disturbed nervous mechanism of the urinary bladder, but no clinically demonstrable lesion in the central nervous system. Of seventy-three patients with cord bladders who registered at the Mayo Clinic during 1921 and 1922, seventeen (23.29 per cent.) were neurologically normal according to the usual tests, symptoms referable to the bladder being the only evidence of disease of the central nervous system. The question arises: Are such symptoms due to a local disturbance in the nerve supply? If so, theoretically the condition of the sensory as well as of the motor fibers of the nerves in question should be investigated.

A review of the literature disclosed comparatively little on the study of bladder sensibility. This investigation was begun in order to determine (1) the response of the normal bladder to touch, temperature and pain; (2) if possible, the sensory changes in neuropathic bladders, and (3) a further point of differentiation of bladder retention due to obstruction, and that due to a lesion in the nerve supply.

GENERAL CONSIDERATIONS

It is conceivable that an anesthetic or hypesthetic bladder is potentially subject to abnormal retention, because of absence of the impulse to initiate the act of micturition, resulting in overdistention, atony and incomplete emptying. It is well known that patients with so-called cord bladders are able to retain urine for long periods without discomfort. In such cases, micturition is often a matter of performing a duty rather than the yielding to an impelling desire. Walker,[1] in 1910, noted the apparent disturbance of sensation in patients with bladder atony, and Caulk and Greditzer,[2] in 1917, in an analytic study of 117 cord bladders, mentioned that the urethras were usually very insensitive and seldom required local anesthesia for examination.

Data obtained in experimental physiology indicate that retention of urine may be wholly dependent on diminished or absent bladder sensi-

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1. Walker, J. W. T.: Atony of the Bladder Without Obstruction or Signs of Organic Nervous Diseases, Ann. Surg. **52**:577-596, 1910.

2. Caulk, J. R., and Greditzer, H. G.: Observations on the Bladder in Diseases of the Central Nervous System, Am. J. Syphilis **1**:42-57 (Jan.) 1917.

bility. Barrington [3] found that division of the posterior sacral (sensory) roots totally abolished micturition. Merzbacher [4] proved the need of sensory impulses for micturition by animal experimentation; a dog whose posterior sacral and coccygeal spinal roots had been cut could wag its tail but could not empty its bladder.

Sensory fibers from the bladder reach the cord by way of the pelvic nerves and the sacral plexus. The hypogastric nerves also convey sensory impulses as far as the inferior mesenteric ganglions, but their existence has not been proved in the sympathetic rami between the inferior mesenteric ganglions and the lumbar cord.[5]

Three centers for reflex bladder contractions have been found: (1) in the lumbar cord,[6] (2) in the hypogastric plexus,[7] and (3) in the inferior mesenteric ganglions.[8] The importance of the center last mentioned is doubtful, as its destruction produces no apparent effect on micturition.[9]

The centers in the hypogastric plexus and lumbar cord are seemingly fertile fields for degenerative process, single or multiple, and not necessarily of wide extent, causing impairment of the function of micturition.

Fig. 1.—Ureteral catheter with white-headed pin fixed securely in the tip.

Unfortunately, an opportunity has not arisen for the pathologic study of a neuropathic bladder, the suspected cause of which is a local or periph-

3. Barrington, F. J. F.: The Nervous Mechanism of Micturition, Quart. J. Exper. Physiol. **8**:33-71, 1915.

4. Merzbacher, L.: Die Folgen der Durchschneidung der sensiblen Wurzeln im unteren Lumbalmarke, im Sacralmarke und in der Cauda equina des Hundes, Arch. f. d. ges. Physiol. **92**:585-604, 1902.

5. Langley, J. N., and Anderson, H. K.: The Innervation of the Pelvis and Adjoining Viscera, J. Physiol. **19**:71-84, 1895-1896. Stewart, C. C.: On the Course of Impulses to and from the Cat's Bladder, Am. J. Physiol. **2**:182-202, 1898-1899.

6. Elliot, T. R.: The Innervation of the Bladder and Urethra, J. Physiol. **35**:367-445, 1906-1907. Stewart, C. C.: Footnote 5, second reference.

7. Griffiths, J.: Observations Upon the Urinary Bladder and Urethra, J. Anat. & Physiol. **29**:61, 254, 1894-1895. Stewart, C. C.: Footnote 5, second reference.

8. Langley, J. N.: Footnote 5, first reference. Nawrocki, F., and Skabitschewsky, B.: Ueber die sensiblen Nerven, deren Reizung Contraction der Blase hervorruft, Arch. f. d. ges. Physiol. **49**:141-158, 1891. Sokownin, N.: Bericht über die physiologischen und histologischen Mitteilungen, Arch. f. d. ges. Physiol. **8**:600-601, 1874.

9. Barrington, F. J. F.: Footnote 3. Mosso, A., and Pellacani, P.: Sur les fonctions de la vessie, Arch. Ital. di biol. **1**:97, 291, 1882; quoted by Harrington.

eral lesion in its nerve supply. Clinically, however, as will be shown in a series of such bladders, sensibility was either diminished or absent and often associated with disturbances in the muscular tone. This must be considered as indicating that those cases of so-called cord bladders, with absence of other evidence of lesions in the central nervous system, are probably dependent on a lesion or lesions affecting the nerve supply of the bladder, either through interference with the vesical center in the spinal cord, or, as would seem more reasonable in view of the otherwise negative neurologic findings, through destruction of the center in the hypogastric plexus, or both.

TECHNIC OF TEST

Tactile Sensation.—By use of a Braasch direct cystoscope, and without anesthesia, the bladders of a number of normal men and women were subjected to sensory tests. A No. 5 ureteral catheter was utilized after an ordinary white headed pin had been securely fixed in its tip. (Fig. 1.) The bladder was moderately distended with water at body

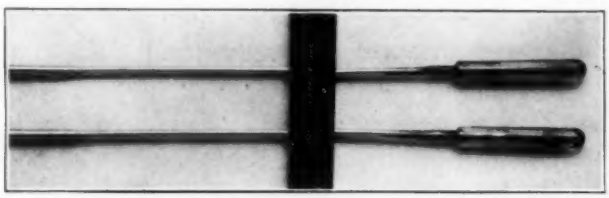

Fig. 2.—Class tip, 2 cm. by 4 mm., fixed to the end of a small gauge steel wire, 30 cm. in length.

temperature, and under visual guidance the white bead was directed over the whole of the bladder mucosa and 2 or 3 cm. of the vesical end of the urethra, the patient having been instructed to signify by saying "now" whenever the touch of the bead was felt.

Thermal Sensation.—The response to thermal stimuli was next investigated. No satisfactory means has been discovered by which the fluid-distended bladder can be studied with rapidly alternating warm and cold esthesiometers. It is conceivable that an electrically warmed instrument could be used, but the concomitant use of a cold stimulus would then be out of the question. Air distension was considered, but discarded because of its impracticability in the male. A uniform method was desirable, suitable for both males and females, and for this reason it was decided that a study of the collapsed bladder with hot and cold knobbed applicators was the best means available. Instruments for this purpose were constructed. At one end of a small gauge steel wire, 30 cm. in length, a glass tip 2 cm. by 4 mm. was fixed. (Fig. 2.) One of

these was placed in a wide mouthed bottle containing a small amount of sterile water heated to about 60 C. Another was similarly placed in water cooled to about 15 C. With the cystoscope in position and the bladder completely emptied of fluid, the instruments were rapidly passed into the bladder and the patient requested to state the resulting sensation. By directing the beak of the cystoscope to various parts of the bladder, a fairly satisfactory estimate of the thermal response was obtained. The small gauge wire was necessary in order to obviate the radiation of temperature through the barrel of the cystoscope to the sensitive urethra. Waltz, in testing the thermal sensibility of the bladder, used a double walled catheter, through which he allowed warm and cold liquids to flow. This method was considered unsatisfactory because of the necessarily prolonged application of the stimulus, and the wide area to which it was subjected. A brief contact with a small area was more desirable in this investigation.

Pain Sensation.—Pain sensibility was studied by means of the white bead and a second catheter in which was fixed a small needle, the point of which barely protruded beyond the catheter tip (Fig. 3). With the bladder distended with water at body temperature and with the catheters

Fig. 3.—Catheter in which a small needle is fixed, the point barely protruding beyond the tip of the catheter.

in place in the double catheterizing guide, the mucosa of the bladder and posterior urethra was gently touched in many areas with the bead and needle point and the patient requested to state whether the resulting sensation was dull or sharp. This means of testing sensation proved to be the most reliable. The bladder was examined in the distended state and under direct vision, neither of which conditions obtained in the investigation of thermal sensation.

Before the bladder sensibility was tested the intravesical tension was recorded by means of a water manometer in order to obtain an accurate clue of the status of the musculature of the bladder, which was considered an index of the integrity of the motor nerves. It was believed that a competent study of the bladder from the neurologic standpoint necessitated an investigation of the motor nerves as well as of the sensory. A discussion of the motor nerves is beyond the scope of this report.

Tactile sensation, a term used for want of a better one, was present in the normal bladders of nineteen patients (eleven women and eight men). It was found that this sense is far less acute in the bladder than in the skin. As a rule, pressure sufficient to produce a slight indentation

of the mucosa was necessary before the stimulus was perceived by the patient. This brings up the question of whether this is not a form of pressure sense rather than touch. The response of the normal bladder to mechanical stimuli has been denied by Zimmermann,[10] who used a stiff pointed catheter. He found the entire urethra sensitive to the manipulation, but believed that the tip did not elicit sensation within the bladder. His observation is of doubtful value as the urethra was not eliminated in the experiment. Under anesthesia, Waltz [11] used a catheter to touch lightly the mucosa and found that certain patients experienced a stinging sensation which they were able to localize in the right or left side of the bladder; but he was unable to draw definite conclusions from his work.

It was found that the sensation for touch was somewhat more acute in the base of the bladder than in the lateral walls and dome. The trigon, the ureteral orifices and the region between them and the internal vesical sphincter were the areas usually most sensitive. On slight withdrawal of the cystoscope, the posterior urethra was brought into view, and it was always found more sensitive than the bladder. The mere touching of the mucosa was slightly painful to certain patients, likened by one to the sensation experienced when the conjunctiva is gently touched. In many instances, no definitely painful sensation resulted from this part of the procedure. Usually, the side of the bladder stimulated could be definitely localized by the patient.

Technical difficulties render the determination of thermal sensibility less accurate than that of touch and of pain. While it has been found from these tests that the sensations of heat and cold are normally present, it has been observed that nerve endings sensitive to thermal stimuli are not always present in the bladder. According to von Frankl-Hochwart,[12] the delicate sensibility of the bladder for temperature is known. Zimmermann denies that differences in temperature are perceptible, but ascribes to a pathologic condition the burning sensation produced by the warm lamp of a cystoscope in contact with the wall of the bladder. Waltz allowed warm and cold water to flow into the bladder through a double-walled catheter and found that differences of 20 C. could not be detected. Prolonged application of cold fluid produced a cold sensation. Hot temperatures were reported as warm. He

10. Zimmermann, R.: Experimentelle Untersuchungen über die Empfindungen in der Schlundröhre und im Magen, in der Harnröhre und in der Blase und im Enddarm, Mitt. a. d. Grenzgeb. d. Med. u. Chir. **20**:445-457, 1909.

11. Waltz, W.: Ueber die Blasensensibilität, Deutsch. Ztschr. f. Nervenh. **74**:278-284, 1922.

12. Von Frankl-Hochwart and Zuckerkandel: Die nervösen Erkrankungen der Blase, Nothnagel's Spezielle Pathologie und Therapie, Vienna, A. Hölder, 1898.

also corroborated Schwenkenbecher's [13] observation that menthol affects the nerve endings for cold specifically, giving a cold sensation.

By using the glass knobbed esthesiometers, it was found that heat was perceptible in every instance in the normal bladders. The thermal sensation, although far less acute than in the normal skin, was present. Cold was not as readily detectable as heat. The temperature of the fluid in which these instruments were immersed was about 60 and 15 C., respectively, but the temperature change was rapid on passing the instrument through the cystoscope, so that the actual temperature at the time of contact with the mucous membrane of the bladder was nearer 45 C. for warm and 25 C. for cold. Too much dependence should not be placed on the thermal findings alone, but this phase of the examination should be considered only in conjunction with the sensory responses to touch and pain. It was interesting to find that thermal sensation was diminished or absent in a number of cord bladders examined.

The process of testing for the sensation of pain is simple, is rapidly accomplished and is believed to be more reliable than tactile and thermal response. The pain sense was definitely present in all of the nineteen normal bladders. Touching the bladder mucosa with the bead may not be without an element of pain, but it is readily distinguishable from the sharp prick of the needle point, except in instances in which hyperesthesia exists, when the dull stimulus may be reported as sharp. Normally, the degree of sensibility was only slightly less marked in the dome and lateral walls than in the base of the bladder. It was found that this part of the examination was prone to cause slight bleeding, which renders it inadvisable to use a lens cystoscope; and the irritation was often followed by viscal spasms. For these reasons, it was made the terminal part of the procedure, and before withdrawing the cystoscope, the bladder was emptied and a small amount of 5 per cent. argyrol was instilled. No harmful results have followed the examination, except in one instance: a patient with cord bladder, complicated by a diffuse cystitis, developed moderately severe pyelonephritis following the test, from which he recovered under the usual treatment.

PATHOLOGIC DISTURBANCES OF SENSATION

The bladders of fourteen patients, twelve men and two women, were examined, in all of whom various disturbances of the urinary function had been diagnosed clinically as cord bladder. Nine of these patients did not have neurologic symptoms; three had syphilis of the central nervous system, and two had myelodysplasia. Tactile sensation was considered normal in five, moderately diminished in seven, and entirely

13. Schwenkenbecher, A.: Ueber Mentholvergiftung des Menschen, München. med. Wchnschr., 1908, ii, 1495-1496.

absent in two. The five patients with normal sensation for touch had associated diminution of sensibility to pain and temperature of varying degree. Three of these had no clinically discoverable organic basis for the nerve disturbance, but the other two, on neurologic examination, were found to have myelodysplasia. Of the group of seven patients with moderately diminished tactile sensation, six had concomitant hypesthesia to temperature and pain, of much the same degree. One, however, had moderately diminished tactile sensation, with practically normal sensation otherwise. Two patients had total loss of tactile sensibility and also insensibility to temperature and pain. One of these had syphilis of the central nervous system, and the symptoms of the other were neurologically negative. In these patients, the dermal distribution of the sacral nerves was tested and retested without the discovery of any other area of anesthesia.

In the same group of fourteen patients with cord bladders, one had normal, six moderately diminished, and seven slightly demonstrable or no thermal sensation. As in the normal, it was not uncommon to find the thermal response more diminished in the upper walls and dome than in the base of the bladder. The dissociation of anesthesia for temperature from that for pain was not observed, although differences in the degree of anesthesia of each were not infrequent in individual instances. In three instances, there was a difference in the sensibility of the right and left halves of the bladder. As might be expected for anatomic reasons, the sensory response to pain closely paralleled that of temperature. It was normal in one instance, moderately diminished in six and markedly diminished or absent in seven. The last group of patients had residual urine in amounts varying from none (in one instance) to 1,200 c.c., averaging 387 c.c. The group of six patients with moderately diminished sensation for pain had residual urine varying from none (in one instance) to 300 c.c., averaging 160 c.c. Although the number of patients is too small to justify a definite conclusion, it is indicated that the amount of residual urine in cases of cord bladder tends to bear a certain relationship to the degree of pain sensibility. The mucosa of the bladder of one patient, a man aged 50, with complete retention, was needled until slight hemorrhage resulted without his perceiving any pain whatever. Likewise, he had an anesthesia for temperature, but the tactile response was normal. He had been subjected to prostatectomy without relief of his retention. The motor fibers to the bladder as well as the sensory were evidently involved, as the intravesical pressure at capacity (1,200 c.c.) registered only 12 cm. of water. The negative results of the examination of his central nervous system, which included a study of the spinal fluid, were interesting.

It has been observed that patients having cord bladders with diminished or absent sensibility may complain of frequent and painful

urination, and it will be found that the sensation of the posterior urethra is intact and usually the site of an inflammatory process. It was not unusual to find the sensation of the posterior urethra obtunded along the bladder sensibility, but an anesthetic urethra associated with normal bladder sensation has not been observed.

In charting the sensory findings, sensation was graded from —4 (total anesthesia) to +4 (marked hyperesthesia). Zero was taken as normal. Tactile sensation is recorded in plain Arabic numerals, thermal sensibility is indicated by Roman numerals, and sensation for pain by enclosed Arabic numerals. Figures 4 to 8 show graphically the variations from normal in the series of fourteen neuropathic bladders with disturbances in sensation. The sensibility of the vesical end of the urethra in each case is also indicated.

REPORT OF CASES

CASE 1.—F. G. H., a man, aged 66, complained of frequent and painful urination of two years' duration. Six months before, he had noticed enuresis, and eight days before, 1,500 c.c. of residual urine had been recovered by catheter. As the prostate was moderately enlarged and possibly obstructing, a suprapubic prostatectomy and later a punch operation were performed, without relief from the retention. Following operation, the cystoscope revealed a moderately relaxed internal sphincter and a marked generalized trabeculation. There was no obstruction. The intravesical tension was abnormally low. The Wassermann reaction on the blood was negative, and the neurologic examination was negative. The bladder sensibility was markedly reduced to touch, temperature and pain (Fig. 4).

CASE 2.—P. A. C., a man, aged 50, had experienced increasing difficulty of urination for eighteen months. The residual urine amounted to 1,200 c.c. The prostate was slightly enlarged, and possibly causing obstruction. A suprapubic prostatectomy was performed without relief from retention. The Wassermann reaction on the blood was negative. The neurologic examination, including study of the spinal fluid, was negative. Bladder sensory tests disclosed normal tactile sensation and practically complete absence of the thermal and pain sensibility (Fig. 5).

CASE 3.—C. S., a man, aged 43, had been troubled with occasional enuresis until the age of 25. He had had attacks of pain in both loins for twenty-two years, at first every two years, recently almost monthly. The stream had never been good, and initial difficulty was marked. Slight dribbling had been present for the last twelve months. There was residual urine of 300 c.c. Cystoscopic examination revealed slight relaxation of the internal sphincter and marked trabeculation; slight diffuse cystitis and bilateral pyelonephritis, and slight enlargement of the prostate, without obstruction. The Wassermann reaction on the blood was negative. The neurologic examination revealed a definite diminution of the deep reflexes in the right lower extremity and slight weakness of the anal sphincter. A diagnosis was made of myelodysplasia. There were no sensory changes in the dermal distribution of the sacral plexus. Sensibility for touch, temperature, and pain was definitely diminished in the right half of the base of the bladder (Fig. 6).

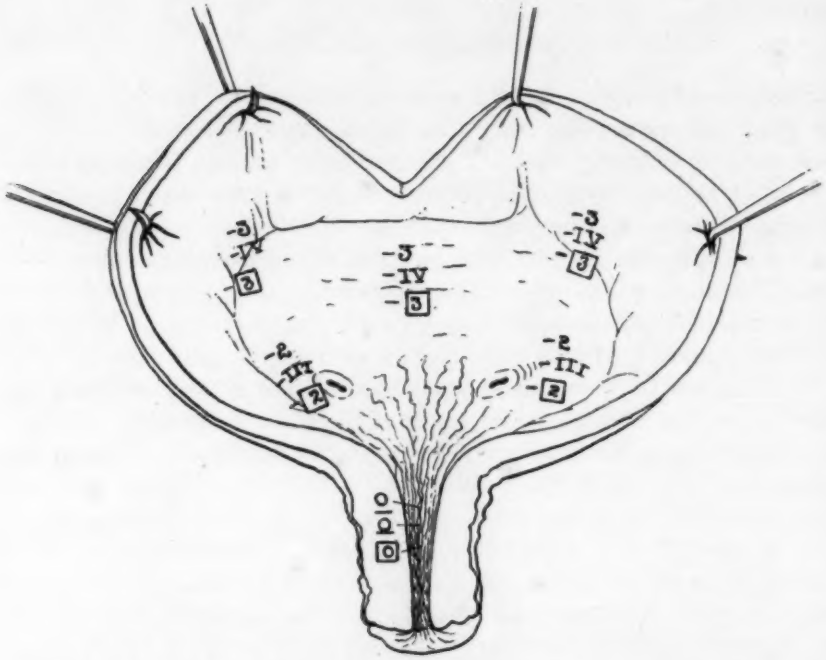

Fig. 4.—Bladder sensibility markedly reduced to touch, temperature and pain. In Figures 4 to 8, tactile sensation is recorded in Arabic numerals; thermal sensibility, in Roman numerals, and sensation for pain by enclosed Arabic numerals.

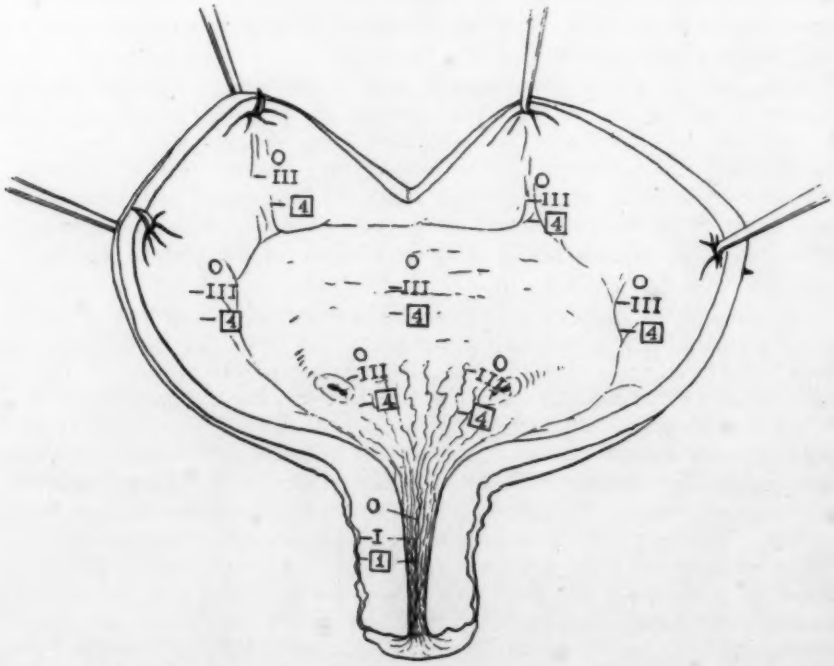

Fig. 5.—Bladder sensory tests disclosed normal tactile sensation and practically complete absence of thermal and pain sensibility.

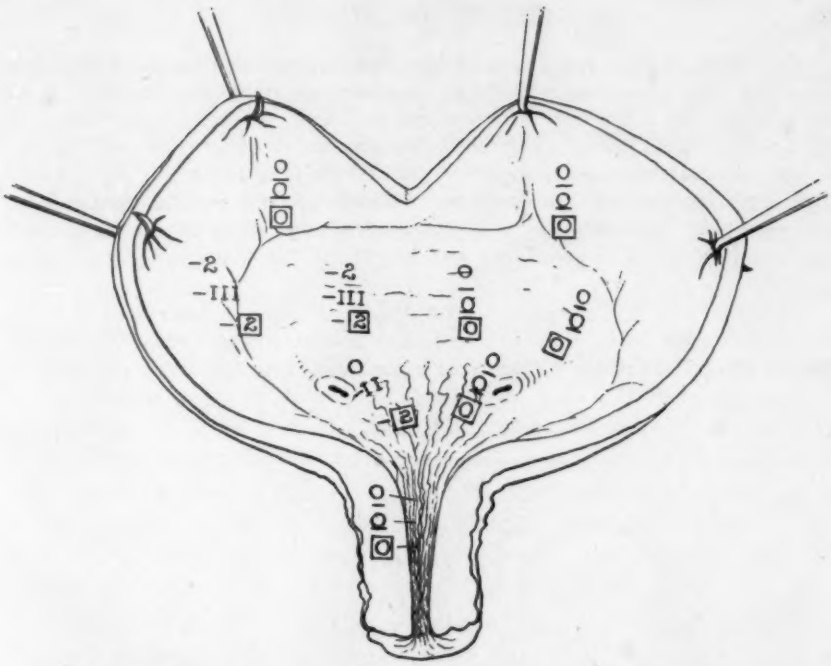

Fig. 6.—Sensibility for touch, temperature and pain definitely diminished in the right half of the base of the bladder.

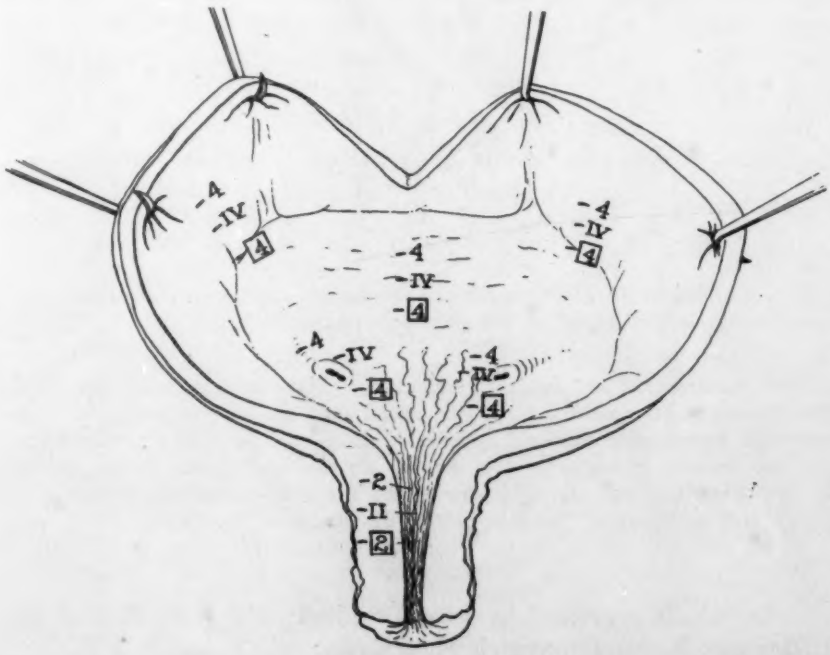

Fig. 7.—Bladder sensibility absent for touch, temperature and pain.

Case 4.—C. F. P., a man, aged 29, had been catheterizing himself every night for seven months because of inability completely to empty the bladder. There was marked initial difficulty and terminal dribbling. On admission, there was 200 c.c. of residual urine. Cystoscopic examination revealed slight enlargement of the prostate without obstruction, and slight relaxation of the internal sphincter. There was no trabeculation. The Wassermann reaction on the blood was negative. The neurologic examination, including study of the spinal fluid, was negative. Bladder sensibility was absent for touch, temperature and pain (Fig. 7).

Case 5.—C. N. McC., a man, aged 46, had had initial difficulty and terminal dribbling fo rtwo years. Recently, he had been unable to micturate. There was 240 c.c. of residual urine. Cystoscopic examination revealed a normal prostate,

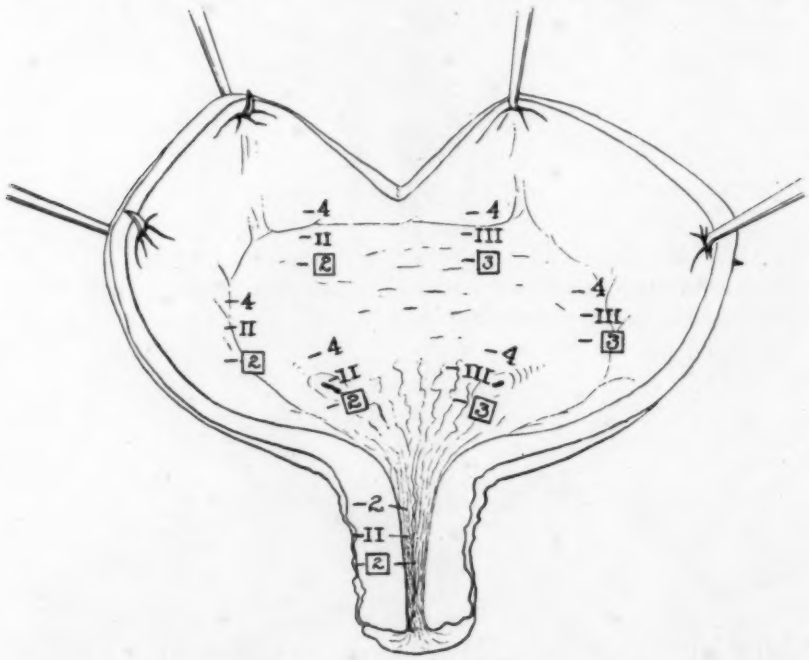

Fig. 8.—Bladder sensibility markedly diminished for touch, temperature and pain, slightly less in degree in the right half of the bladder.

marked trabeculation and moderate relaxation of the internal sphincter. The Wassermann reaction on the blood and spinal fluid was strongly positive. The neurologic examination disclosed syphilis of the central nervous system. There were no sensory changes in the dermal distribution of the sacral plexus. Bladder sensibility was markedly diminished for touch, temperature and pain, slightly less in degree in the right half of the bladder (Fig. 8).

SUMMARY

A technic is suggested by which, clinically, the sensibility of the bladder may be more accurately studied.

The sensations of touch, temperature and pain were found to be present in the bladders and vesical ends of the urethras of eleven women

and eight men, all of whom were considered normal. While the number examined does not warrant definite conclusions, it would seem that the sensations mentioned are discernible in the normal bladder and to a greater degree in the posterior urethra.

The sensibility of neuropathic bladders of fourteen patients was investigated. Nine of these patients had no clinically demonstrable lesion of the central nervous system; five had positive evidence of disease in the brain or spinal cord or both. The discovery of sensory changes in the first group of nine favors the opinion that two main types of neuropathic bladders exist: (1) those resulting from some disturbance in the peripheral or local nervous mechanism, and (2) those dependent on pathologic conditions of the central nervous system.

Sensory changes may vary from complete anesthesia to hyperesthesia. Dissociation of tactile anesthesia from thermal and pain sensibility is not uncommon. Dissociation of thermal from pain anesthesia was not noted. Differences in the sensibility of the right and left halves of the bladder have been observed. Diminished sensation of the bladder may exist with normal sensation of the posterior urethra. The converse has not been observed.

It is sometimes difficult or impossible to state whether urinary retention in a given case is due to a questionable obstruction or dependent on a disturbed nervous mechanism. The study of the bladder sensibility is believed to yield information of definite value in the differential diagnosis of these conditions. The examination of the bladder from the neurologic standpoint should include a study of the sensory as well as of the motor nerve supply.

The localization of lesions in the peripheral or local nerve supply of the bladder was not attempted as the opportunity has not presented itself for the pathologic study of such bladders.

REGENERATION OF THE VAS DEFERENS*

H. C. ROLNICK, M.D.
Associate in Genito-Urinary Surgery, Northwestern University Medical School
CHICAGO

The reproductive and regenerative capacity of the various epithelial lined structures, such as the bladder, urethra, ureter and fallopian tubes, is well known and forms a basis for much of the surgery of these structures. The vas deferens, an epithelial lined duct, follows the same law and has equal powers of regeneration.

That the vas will regenerate itself and restore continuity of its lumen when this has been temporarily, or sometimes even when it is permanently obstructed is taken into account in the sterilization of criminals and defectives and in the Steinach operation; for not only is the vas ligated with nonabsorbable material but it is also resected and a lateral apposition of the severed ends made to insure against restoration of the lumen.

Even after extensive trauma, division or resection of the vas for as much as from 1½ to 2 inches (3.7 to 5.0 cm.) of its length, regeneration and restoration of the continuity of the lumen can occur. This regeneration, which is aided materially by the sheath of the vas deferens, the former acting as a splint promoting and directing the path for epithelization, is very similar to the regeneration of bone through the periosteum.

The vas can also be reunited after division or resection by the suturing of the cut ends, suture of the sheath aiding the restoration of the lumen.

Although these facts may be of more or less general knowledge, little in the way of clinical observation, experience or experimental work on this subject has been recorded in the literature.

For the purpose of determining these facts, the following experiments were performed on a series of twenty-five dogs, in all forty-eight operations on as many vasa:

1. Ligation of the vas deferens. 2. Multiple longitudinal and oblique incisions of vas. 3. Transverse incisions. 4. Transverse section—complete division. 5. Suture of vas in skin or subcutaneous tissues—left horsehair in vas. 6. Transverse section, complete division and suture of severed ends. 7. Resection. 8. Resection and suture.

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* Read before the Chicago Urological Society, Oct. 25, 1923.

* From the Department of Genito-Urinary Surgery, Northwestern University Medical School.

The animals were killed from eight to forty-three days after operation and the vasa removed. The only end-result determined was whether the lumen was patent after trauma or ligation or whether the continuity of the lumen had been restored where it had been severed. In the first nine dogs, water was injected through the vas

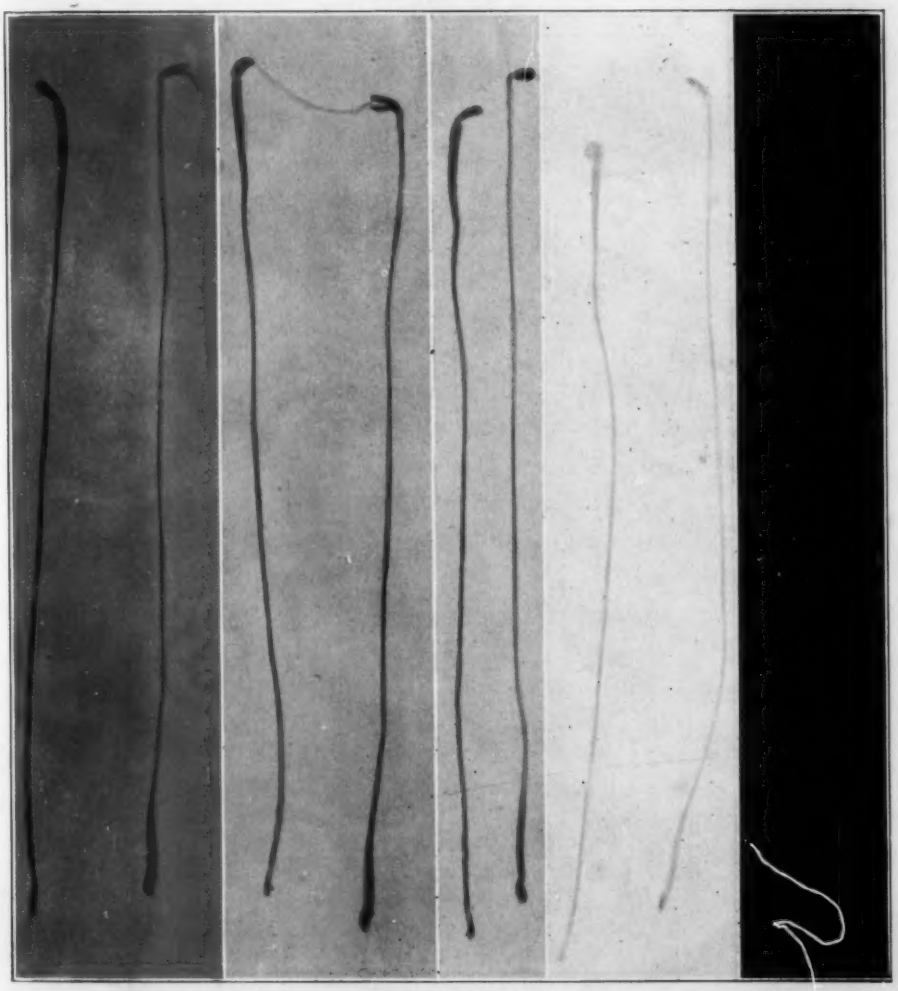

Fig. 1.—Dog 10: The sections were injected with 25 per cent. sodium iodid solution. Some were removed in toto, i. e. the entire vas, testicle and epididymis, and in others, the vas only was removed. Bilateral transverse section; complete division, but sheath not completely severed; base of sheath left intact; removed thirty-two days later; result: complete union; restoration of lumen.

to determine whether there was occlusion. A 25 per cent. solution of sodium iodid was injected into the others after removal, and a roentgenogram was then made of the vas to determine the end-results.

SUMMARY OF OPERATIONS ON THE VAS

1. *Ligation of the Vas With Catgut; One Ligature on Each Vas (Six Operations).*—Dog 7: Double ligation was performed. The vasa were removed thirty-eight days later. Both vasa were patent.

Dog 9: Double ligation was performed. The vasa were removed thirty-one days later. Both vasa were patent.

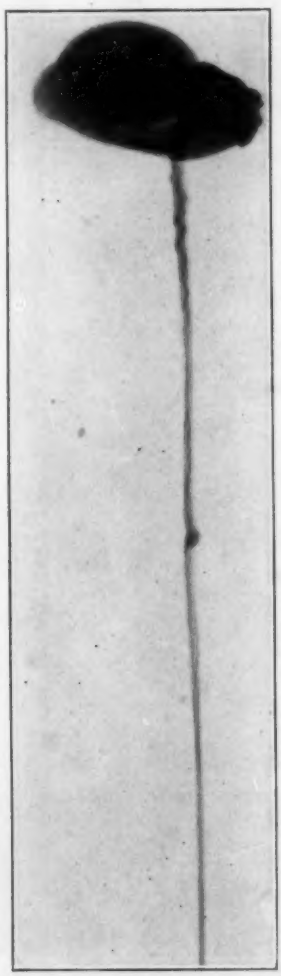

Fig. 2

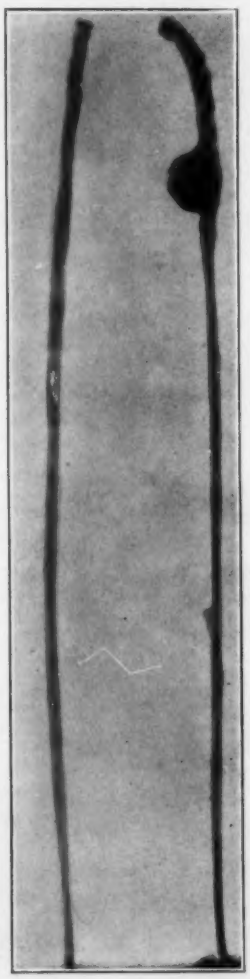

Fig. 3

Fig. 2.—Dog 15: The left vas was ligated with heavy catgut, being removed twenty-three days later. Result: Restoration of lumen.

Fig. 3.—Dog 16: In the right vas, multiple longitudinal and oblique incisions were made, with removal twenty-one days later; result: patency. The left vas was sutured to the skin and a horsehair left in the lumen, with removal twenty-one days later; result: patency.

Dog 14: The right vas was ligated. On removal twenty-two days later, the vas was patent; the lumen normal.

Dog 15: The left vas was ligated. On its removal twenty-three days later, roentgen-ray examination showed that it was patent. The lumen was normal.

The results here are uniform; in every case the lumen of the vas was restored.

In one or two of these experiments, there were some adhesions to the surrounding tissues. One could note a definite thinning, transparency and slight indentation at the point of ligature in the fresh specimens. This did not present itself after the tissues had been placed in fixing solution or after injection of the vas.

2. *Multiple, Longitudinal and Oblique Incisions of Vas Extentive Trauma (Five Operations).*—Dog 1: The right vas was removed thirty-eight days later. The lumen was patent.

Dog 2: Bilateral incisions were made. On removal of the vasa thirty-three days later, the right vas had a patent lumen; the left vas, an occluded lumen.

Dog 3: Multiple longitudinal incisions were made in the left vas which was separated from the sheath. The lumen was occluded.

Dog 16: Right vas was removed. There were many adhesions but the lumen was patent (roentgen-ray examination).

In three of five operations, the lumen remained patent following extensive trauma in the form of multiple incisions.

3. *Multiple Transverse Incisions of the Vas (One Operation).*—Dog 3: The right vas was removed after thirty-two days. The lumen was occluded.

Only one operation was performed. In previous experiments, not recorded here, multiple transverse incisions, almost complete division in numerous places, always resulted in occlusion of the lumen.

4. *Transverse Section—Complete Division of the Vas (Thirteen Operations).*—This series was divided into two parts:

(*a*) The vas was divided, lifted out and separated from the sheath; or vas and sheath both severed (six operations).

Dog 1: The period was thirty-eight days. The transverse section of the left vas was made and it was separated from the sheath. The lumen was occluded.

Dog 5: There was bilateral division of the vas, which was separated and lifted out of sheath. The period was forty-three days. In the left vas, there was fibrous union; in the right, lateral union.

Dog 6: The period was forty-three days. Bilateral transverse division of the vas and also of the sheath was made, with some hemorrhage. In the left vas, there was impermeable, fibrous union; in the right vas, no union.

Dog 20: The right vas was divided, and the sheath also severed. After twelve days, there was no union (roentgen ray).

(*b*) The vas was divided. The sheath was not completely severed. The posterior surface was left intact and deferential vessels were not severed. All the operations were bloodless. The vas was not pulled out of the sheath. (Seven operations.)

Dog 10: Bilateral division was made. The sheath was not completely severed. After thirty-two days, both vasa were patent and united.

Dog 13: Division of the right vas was made. After twenty-three days, there was no union. The scar was impermeable.

Dog 14: Division of the left vas was made. After twenty-two days, the lumen was patent, and there was complete regeneration.

Dog 18: Division of the left vas was made. After eleven days, there was complete regeneration and the lumen was patent (roentgen ray).

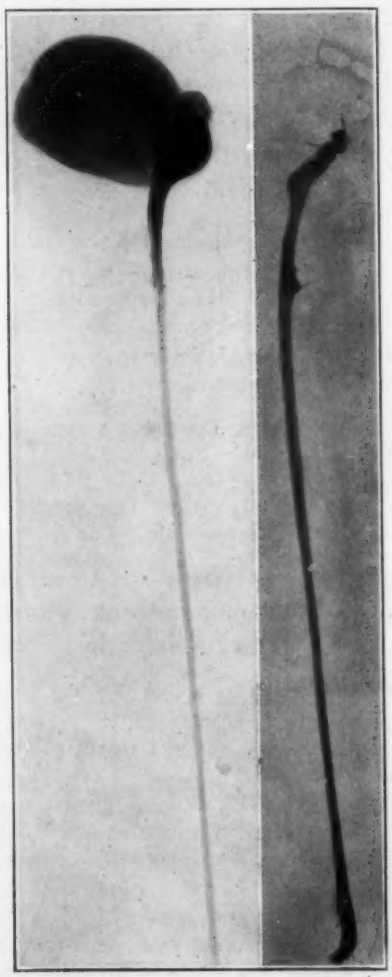

Fig. 4.—Dog 18: Left vas completely divided by transverse section; removed sixteen days later; result: complete union. Right vas—Simply X-Ray of vas and epididymis; this side not operated upon.

Dog 19: Division of the right vas was made. After eleven days, there was complete regeneration and the lumen was patent.

Dog 20: The left vas was divided. After twelve days, there was complete regeneration. The lumen was patent (roentgen ray).

In this series of experiments, the end-results show a marked variance in those in which the sheath had been left partly intact and in the others in which the sheath had been completely severed or the cut ends of the vas separated from the sheath.

In all the six in which the vas had been divided and separated from the sheath, or the vas and sheath were both severed, there was either no union or a fibrous union. Since these operations were recorded, six similar operations in which there was complete division of the vas and sheath showed a restoration of the continuity of the lumen in two instances.

However, in six of the seven in which the vas had been divided, and part of the sheath left intact, the vas had regenerated itself and the continuity of the lumen was restored. In all these cases, particular care was taken that the deferential vessels be not injured. The operation was bloodless. The vas was not separated from the rest of the spermatic cord.

These results bring out clearly the importance of the sheath of the vas and the deferential vessels. When the operation was bloodless and the sheath not completely severed, restoration of the lumen occurred very rapidly in all but one of the seven operations. Although only seven experiments are recorded, more than twice that number of operations were performed. In many of these cases in which the sheath had been left partly intact, no evidence could be found on removal of the vas that anything had been done, and the possibility of a mistake, either in the identity of the animal or in the operation, was seriously considered. The number of the dog was tattooed on one ear and there could hardly be a mistake, but despite this, these experiments were repeated and the dogs segregated.

In the cases reported here, it was also noted that no operation wound of the vas could be found in two instances and that even as early as twelve days after complete division, with part of the sheath left intact, restoration of the lumen had occurred.

5. *Sutured Vas to Skin or Subcutaneous Tissue or Left Foreign Body; Horsehair in Lumen (Seven Operations).*

Dog 16: The left vas was sutured to the skin and horsehair was left in the lumen. Roentgen-ray examination after twenty-one days showed a patent lumen. The vas showed a grayish discoloration.

Dog 17: The period was twenty-one days. Horsehair was left in on the left side, which was thrown back. The right was incised and sutured into the skin. Both vasa were patent (roentgen rays).

Dog 21: The period was eight days. The animal died of pneumonia. In the left vas, horsehair was left in. The lumen was patent. There were changes in the vas. The right vas was incised and sutured to the subcutaneous tissues. The lumen was normal and patent.

Dog 23: The period was twelve days. On the left, the vas was sutured in the skin. Adhesions formed. On the right, sutures were made through the vas and in the skin. There was union. The lumen was patent. There was an opening in the lumen when it was under pressure, and fluid leaked out. Both vasa were examined by roentgen ray.

Although we have no report here of microscopic sections made, undoubtedly trauma, suture or foreign body in the vas produces some changes; but in themselves they do not cause occlusion.

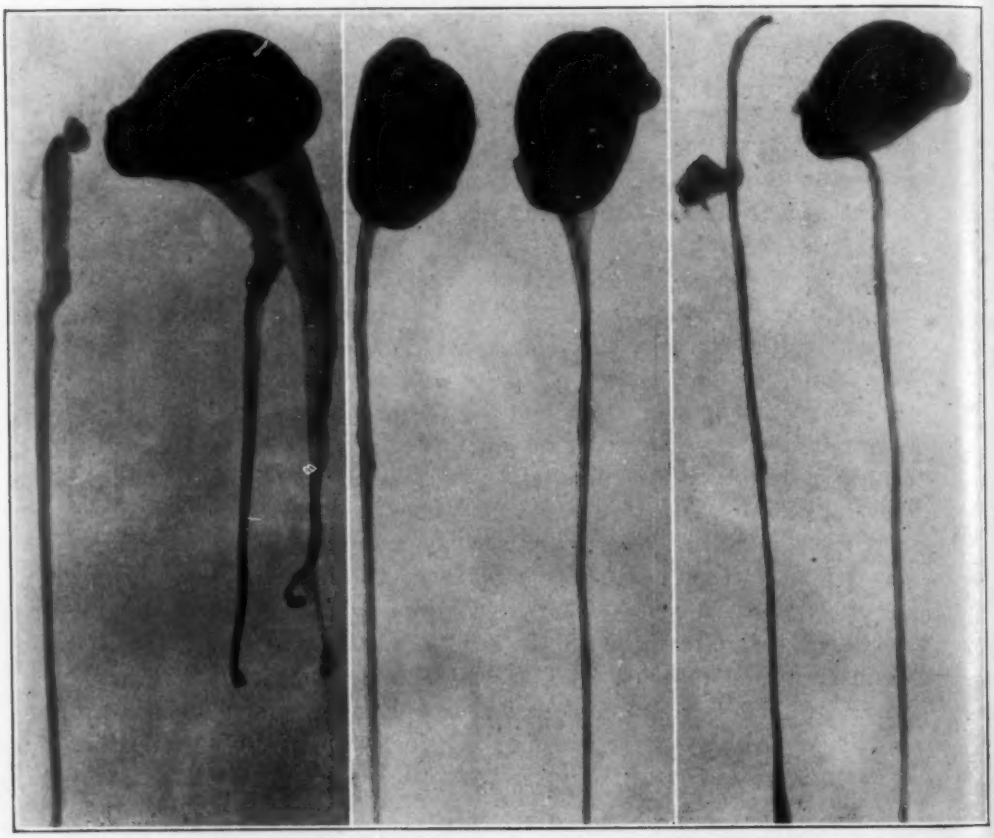

Fig. 5.—Right: Dog 17: Right vas incised and sutured in skin; removed twenty-one days later; result: Lumen normal and patent. A horsehair was inserted in the left vas for a considerable distance and left in; removed twenty-one days later; result: lumen normal and patent.

Center: Dog. 23: Left vas sutured into skin; removed twelve days later; result: patency. Sutures were made through the right vas and in the skin; result: Patency. Following the pressure of injection, the cut in the lumen reopened and fluid leaked out (not shown in roentgenogram).

Left: Dog 20: Complete division of right vas by transverse section. The vas was pulled out of sheath; removed twelve days later; result: no union. Complete division of the left vas was made by transverse section. The vas was not pulled out of the sheath and part of the sheath was intact; removed twelve days later; result: lumen restored, with union.

6. *Transverse Section of Vas—Complete Division of Vas and Sheath and Suture of Severed Ends.*—Suture was made with 00 catgut, a round cutting needle and only one suture, which united the sheath or placed the cut ends in apposition. No attempt was made to follow any particular technic. The cut ends of sheath were sewed together in the three operations.

Dog 13: Left vas was bisected transversely. After twenty-three days, there was no union, with secondary infection, adhesions, infection of testicle and epididmyis.

Dog 15: The right vas was bisected. After twenty-three days, there was no union.

Dog 27: The left vas was divided and vas and sheath were sutured. After seventeen days, the lumen was patent, and there was complete union (roentgen ray).

No particular technic was employed, but in the three experiments, the cut ends of the sheath were sutured together. Restoration of the lumen resulted in one case.

7. *Resection of Vas (Three Operations).*—Dog 8: Bilateral resection of one-half inch (1.3 cm.) of both vasa was made, but the sheath was left intact. The vas was pulled out of sheath and the cut ends were thrown back into the sheath. Both were patent after thirty-eight days.

Dog 19: The left vas was bisected as in Dog 8, with a one-eighth inch (0.3 cm.) resection. After eleven days, the lumen was patent.

With the sheath as a splint, even as early as eleven days after resection, the continuity of the lumen had been restored.

8. *Resection and Suture (Ten Operations).*—Sutures were made with a round cutting needle and one suture of No. 00 catgut to allow for apposition of cut ends. In some, suture of the cut ends of vas alone was made, and in others, both the cut ends of the vas and the sheath were sewed together.

Dog 24: On the left, resection of one-fourth inch (0.6 cm.) of vas was made, and the united cut ends of vas were separated from the sheath. After eleven days, there was some union but it was incomplete.

Dog 25: On the right, one-half inch (1.3 cm.) of the vas and sheath was resected, and the cut ends of the vas without the sheath were sutured. After eleven days, there was lateral union. The scar was impermeable (roentgen ray). On the left, the same technic as above was employed, with suture of vas and sheath. There was no union after eleven days.

Dog 26: Bilateral resection of vas and sheath was made for one-fourth inch (1.6 cm.) and both vas and sheath were sutured. Both sides were infected, and there was no union, after sixteen days.

Dog 27: The right vas was pulled out of the sheath and one-half inch (1.3 cm.) resected. The cut ends of the vas were sutured together with the separated sheath. After seventeen days, there was scar tissue about the wound but the lumen was patent (roentgen ray).

Dog 28: Both vasa were resected one-half inch (1.3 cm.) and sutured with sheath. In the right vas, there was fibrous union; the left vas was patent and normal after seventeen days.

Dog 30: Both vasa were resected one-fourth inch (0.6 cm.); each vas was pulled out of sheath and the vas ends and sheath were sutured. After eighteen days, both lumina were patent as though nothing had been done. In this case,

the sheath was not completely severed, the vas being pulled out of the sheath and then the cut ends thrown back into sheath and sutured together.

In four of ten in which the resected ends were sutured, regeneration took place. In every one of these four, the ends of the sheath had also been sutured together or the sheath had not been completely severed.

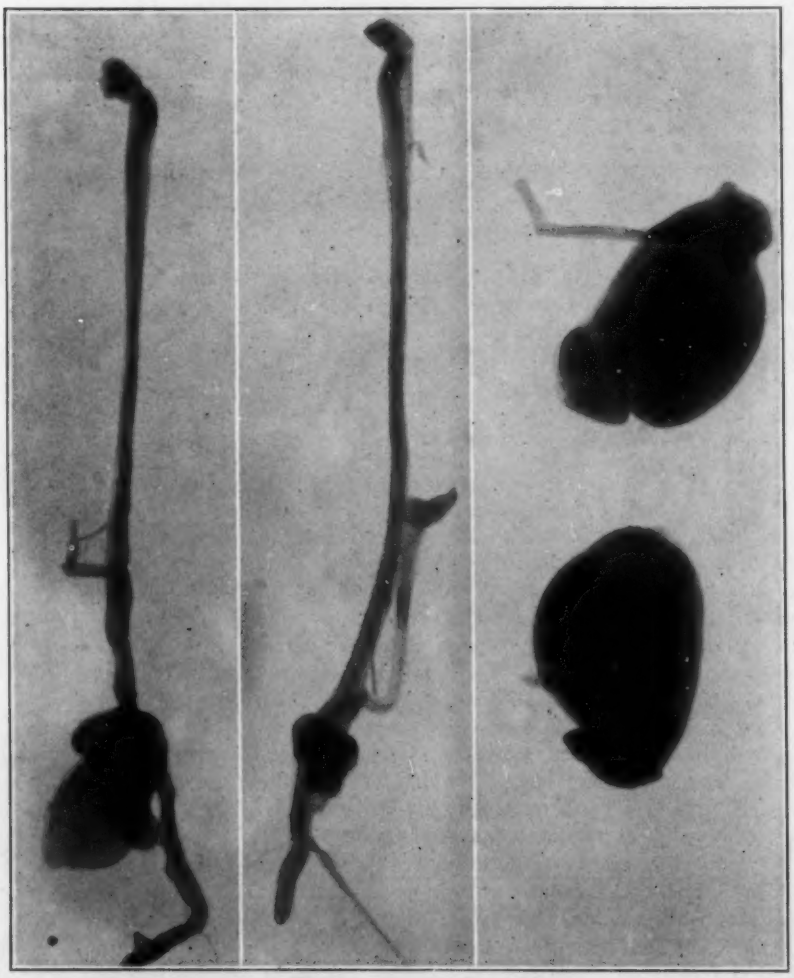

Fig. 6.—Left: Dog 25: Right vas resected one-half inch and cut ends sutured without the sheath; removed eleven days later; result: no union. Center: Dog 24: Left vas resected one-quarter inch and cut ends sutured with catgut ouside of sheath; removed eleven days later; result: no union. Right: Epididymis (Dog 24).

At various times during the last thirty to forty years, different methods for suturing the vas have been recommended, all writers

laying stress on the need for some sort of a splint to allow perfect end-to-end apposition and the maintenance of this support for a few days.

The experiments here recorded bear out the importance of the sheath of the vas in suturing the cut ends; the technic followed is only of secondary importance. All that is necessary for a successful result is the union of the cut ends of the sheath. Without the suture of the sheath, the possibility of the restoration of the lumen is considerably lessened.

ROENTGEN-RAY EXAMINATION OF TESTICLE AND EPIDIDYMIS

During the course of injecting the vas with sodium iodid solution, preliminary to making the roentgenograms, attempts were made to inject the fluid into the epididymis and, if possible, the testicle also. It was repeatedly found that no fluid could be injected beyond the tail of the epididymis, irrespective of the degree of pressure and force exerted and that it was impossible to demonstrate the minute structure of the epididymis beyond the globus minor. An attempt was made to demonstrate the minute structure of the testicle by injecting fluid at the globus major into the testicle direct. The entire testicle filled up with the fluid and showed a dense shadow but no minute outline.

SUMMARY

The vas is able to regenerate and undergo repair following extensive trauma in the form of multiple longitudinal and oblique incisions. Following multiple transverse incisions, restoration of the lumen does not occur.

Ligation with absorbable material is only a temporary measure. In all six experiments in which the vas was ligated with catgut, restoration of the lumen took place. This will also occur in a certain number of cases in which even nonabsorbable material is used.

The presence of a foreign body in the vas for a considerable length of time does not in itself produce occlusion of the lumen. Neither does occlusion occur when the vas is sutured into the skin or exposed outside of the skin for a number of days.

The vas will regenerate itself if divided or resected for as much as one-half inch of its length provided the sheath is left partly intact or reunited if severed. Without the sheath, regeneration occurs only in a small percentage of cases.

Suture of the severed ends of the vas does not require any special technic. The one point of particular importance is the coaptation of the severed ends of the sheath.

CONCLUSIONS

The results gained in these experiments emphasize (1) the regenerative powers of the vas and its ability to resist trauma and restore continuity of its lumen; (2) the importance of the sheath of the vas, acting as a splint and making a path for epithelization, and (3) possibility of restoration of lumen, which is enhanced, when the deferential

Fig. 7

Fig. 8

Fig. 7.—Dog 27: Complete transverse section and division of left vas and sheath, then suture of cut ends of vas and sheath; removed seventeen days later; result complete union.

Fig. 8.—Dog 27: Right vas and sheath resected one-half inch and cut ends sutured; removed seventeen days later; result: complete union.

vessels are not injured, for they also act as a splint aside from supplying blood to the vas.

HISTORY OF OPERATIONS

Dog 1.—Operation was performed, June 8, 1923; the tissues were removed, July 16, after thirty-eight days. Longitudinal and oblique multiple incisions of the right vas were made. After removal, the lumen was patent. Water could be injected through the vas. There was some evidence of scar on the surface, but there were no adhesions. The left vas was divided transversely, separated from and pulled out of the sheath. The lumen was occluded. There was a band of fibrous tissue uniting cut ends.

Dog 2.—Operation was performed, June 13, 1923; the tissues were removed, July 16, thirty-three days later. Bilateral multiple longitudinal and oblique incision of the vas was made. In the right vas, the lumen was patent. Water can be injected through it. The left vas was occluded.

Dog 3.—Operation was performed, June 14, 1923; the tissues were removed, July 16, thirty-two days later. In the left vas, multiple longitudinal and oblique incisions were made. The vas was pulled out of its sheath and separated from it. The lumen was occluded. Water did not go through. In the right vas, multiple transverse incisions were made. The vas was pulled out of and separated from the sheath. The lumen was occluded.

Dog 5.—Operation was performed, June 28, 1923; the specimens were removed, August 10, after forty-three days. Bilateral complete division of the vas was made, and both sides were pulled out and separated from the sheath. The left was impermeable, with many fibrous adhesions and fibrous union. The right showed lateral fibrous union and was impermeable.

Dog 6.—Operation was performed, June 28, 1923; the specimen was removed, August 10, after forty-three days. A bilateral complete division of the vas was made, and the vas was separated from and pulled out of its sheath. The left was impermeable, with fibrous union. On the right, there was no union.

Dog 7.—Operation was performed, Aug. 3, 1923; the specimen was removed, August 10, thirty-eight days later. Bilateral ligation was made with catgut No. 2, one ligature on each vas. Both lumina were patent and no adhesions were present. There was slight indentation and thinning of the vas at the point of ligature. The latter could not be noted after specimens had been fixed.

Dog 8.—Operation was performed, July 3, 1923; sections were removed, August 10, thirty-eight days later. One-half inch of each vas was resected. The sheath was not divided, but was nicked. The vasa were pulled out and resected and then the cut ends were allowed to go back into the sheath. There was complete regeneration of both sides. Both lumina were patent. Water went through both sides.

Dog 9.—Operation was performed, July 27, 1923; specimens were removed, August 27, thirty-one days later. Bilateral ligation with No. 3 catgut was made, one ligature on each vas. Both lumina were patent. There were no adhesions. Slight indentation and thinning of the coat of the vas at the point of ligature were noted.

Dog 10.—Operation was performed, July 27, 1923, with removal, August 28, thirty-two days later. Bilateral complete transverse section of the vas was made. The vas was not pulled out of its sheath, which was not completely divided, the posterior surface being left intact and the deferential vessels not cut; and the structures were not separated from the rest of the cord. Both

lumina were patent. Injection of 25 per cent. sodium iodid was made and a roentgenogram was taken.

Dog 13.—Operation was performed, Aug. 6, 1923, with removal, August 29, twenty-three days later. A transverse section of the right vas was made, with complete division, as in Dog 10. The wound was infected. There was no union. There was complete division and suture of the left vas and sheath with

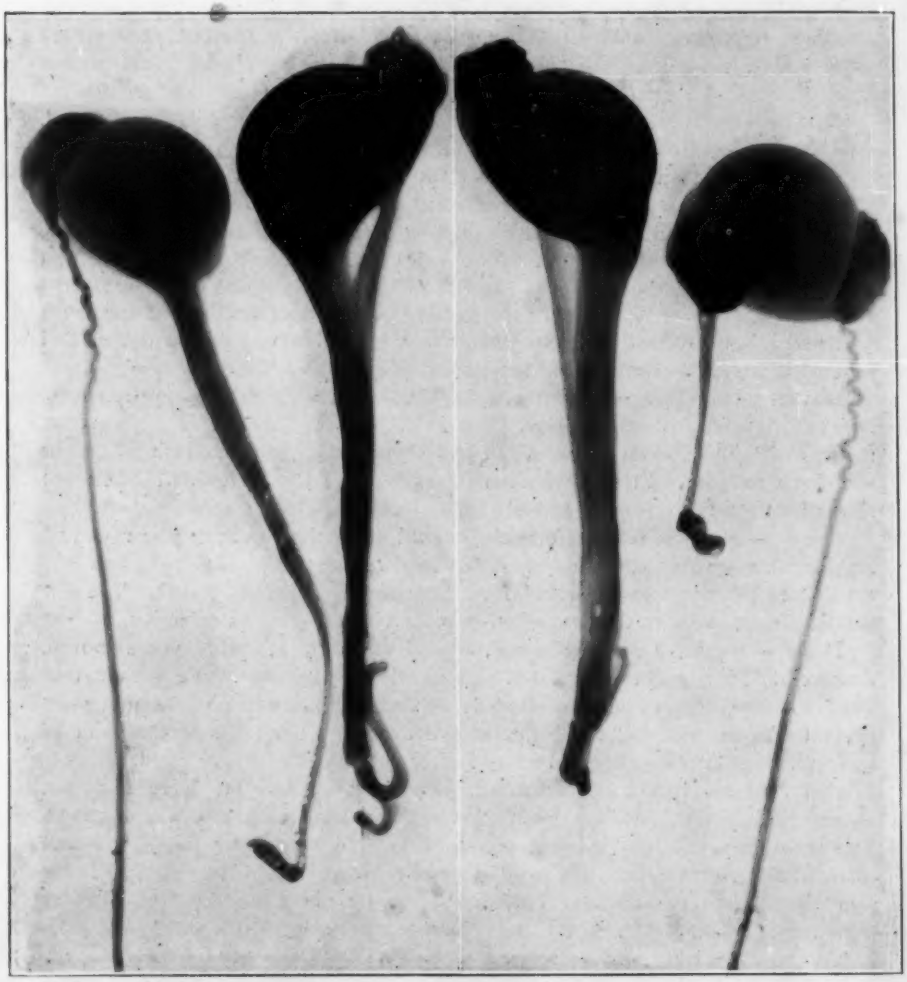

Fig. 9.—Epididymis and testicle.

No. 00 catgut. Secondary infection of wound, testicle and epididymis was found. There was no union.

Dog 14.—Operation was performed, Aug. 6, 1923, with removal, August 28, twenty-two days later. In the left vas, transverse section with complete division of the vas was made. The sheath was severed transversely but left united at the base. The deferential vessels were not injured. The operation was bloodless. Complete regeneration ensued. The point where the vas had been severed could

not be found. In the right vas, ligation was made with catgut No. 1, one ligature. The lumen was found to be patent, with slight indentation and thinning at the point of ligature. After the sections had been hardened, the point of ligature could not be located.

Dog 15.—Operation was performed, Aug. 6, 1923, with removal, August 29, twenty-three days later. The left vas was ligated with catgut, one ligature. The lumen was patent (roentgen ray). Transverse section of the right vas was made, with division and suture with No. 00 catgut. The vas was pulled out of the sheath and cut, the ends being united with a round needle and one suture. There was no union, fibrous tissue adhesions were present.

Dog 16.—Operation was performed, Aug. 8, 1923, with removal, August 29, twenty-one days later. In the right vas, multiple, longitudinal and oblique incisions were made. The lumen was patent. Water went through. The left vas was sutured to the skin and a strand of horsehair left in the lumen. The horsehair came out, and many adhesions were present, but the lumen was patent.

Dog 17.—Operation was performed, Aug. 8, 1923, with removal, Aug. 29, after twenty-one days. A horsehair was left in the lumen of the left vas, and the vas was allowed to remain in the sheath. The horsehair remained in the lumen, which was patent. The vas showed some grayish discoloration. The right vas was incised and sutured into the skin. The lumen was patent, with many adhesions. Sodium iodid was injected in the lumen and a roentgenogram was taken.

Dog 18.—Operation was performed, Aug. 13, 1923, with removal, August 29, after sixteen days. Transverse section of the left vas with complete division was made. The vas was not pulled out of the sheath. The posterior surface of the sheath was not divided, and the deferential vessels were not cut. The lumen was patent, with complete union.

Dog 19.—Operation was performed, Aug. 13, 1923, with removal, August 24, after eleven days. A transverse section of the right vas was made, with complete division within sheath, which was not severed completely. The blood vessels of the vas were not cut. There was complete regeneration. The lumen was patent. The left vas was resected for one-eighth inch, the sheath being left intact and the vas thrown back in the sheath. There was complete regeneration. The lumen was restored and patent.

Dog 20.—Operation was performed, Aug. 17, 1923, with removal, August 29, twelve days later. Transverse section of the right vas was made, with complete division, and the vas was pulled out of the sheath. There was no union. Transverse section of the left vas was made, with complete division. The vas was left in situ and the sheath was not completely severed, the base being left intact. The blood supply was intact, and there was no hemorrhage. Complete regeneration ensued. The lumen was restored and was patent.

Dog 21.—Operation was performed, Aug. 17, 1923, and the dog died, August 25, after eight days. In the left vas a horsehair was inserted and left in. The lumen was found to be patent, but showed changes. The right vas was incised and sutured to subcutaneous tissues. The lumen was normal and patent.

Dog 23.—Operation was performed, Aug. 17, 1923, with removal, August 29, twelve days later. The left vas was sutured into the skin. There were adhesions, and the lumen was patent. In the right vas, sutures were made through the vas and in the skin. Many adhesions resulted, but the lumen was patent.

Dog 24.—Operation was performed, Aug. 20, 1923. Sections were removed, August 31, eleven days later. The left vas was pulled out of the sheath, and resected for one-fourth inch, and the cut ends united without the sheath. There was no union, and but slight adhesion.

Dog 25.—Operation was performed, Aug. 20, 1923, with removal, August 31. The right vas was resected one-half inch and pulled out of the sheath, and the severed end were sutured with catgut No. 00.

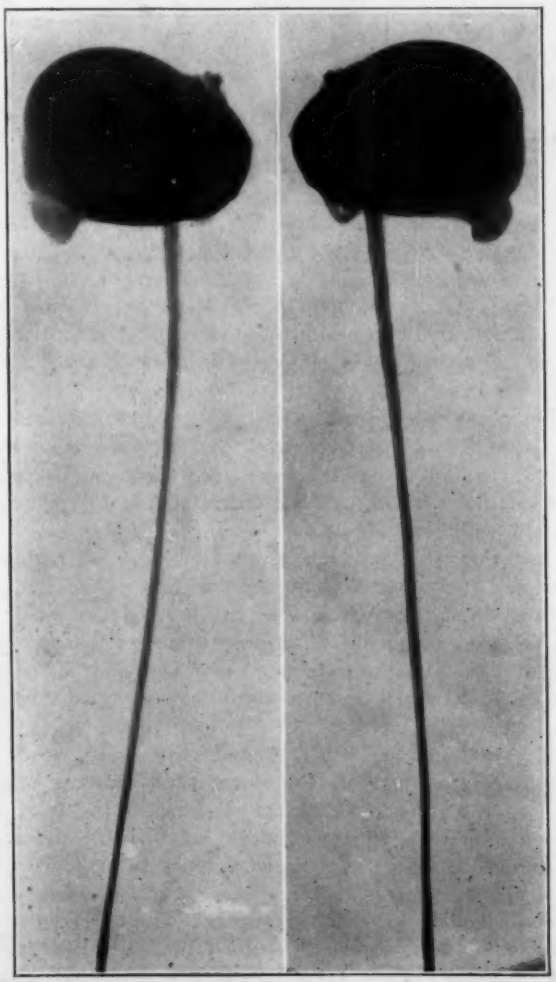

Fig. 10.—Epididymis. Roentgenograms show definitely that no fluid can be injected beyond the globus minor.

There was no union, but the ends of the vas separated (roentgen ray). The left vas was resected for one half inch, then the cut ends of the vas and sheath were sutured, and the vas was thrown back in the lumen of the sheath.

There was no union. The ends of the vas separated.

Dog 26.—Operation was performed, Aug. 20, 1923, with removal, September 5, sixteen days later. Both vas were resected for one quarter inch then each vas sutured and sheath were sutured together.

Both wounds were found infected, and there was no union.

Dog 27.—Operation was performed, Aug. 21, 1923, with removal, September 7, seventeen days later. In the left vas, there was complete division, with section of both vas and sheath—then suture of the cut ends of the vas and sheath with catgut No. 00.

Complete union resulted, with regeneration (roentgen ray).

The right vas and sheath were resected for one-half inch. The cut ends of the vas and sheath were sutured with catgut No. 00. Complete union resulted, with much scar tissue about the wound (roentgen day).

Dog 28.—Operation was performed, Aug. 21, 1923, with removal, September 7, seventeen days later. Bilateral resection of one-half inch of each vas and sheath was made. Then the cut ends of vas and sheath were sutured with catgut No. 00.

The right vas showed scar tissue about the wound. The lumen was not restored and was occluded.

The left vas showed complete regeneration, with perfect union and restoration of the lumen.

Dog 30.—Operation was performed, Aug. 22, 1923, with removal, September 10, eight days later. Both vas and sheath were resected for one-quarter inch and the cut ends of vas and sheath were sutured together with No. 00 catgut. On both sides there was complete regeneration. Both lumina were patent. No scar at point of operation could be found.

MULTIPLE PRIMARY CANCERS

WITH REPORT OF A CASE

LOUIS HERLY, M.D.

NEW YORK

Multiple primary cancers arising in one organ are not very common; multiple primary cancers occuring in several organs are comparatively rare; and a combination of both these forms is sufficiently unusual to merit recording in the literature.

Of 1,664 cases of mammary cancer tabulated by Gross,[1] only two were bilateral in origin, Billroth [2] met with three instances of this kind in 245 mammary cases. According to Nichols,[3] of 685 necropsies for cancer in Montreal hospitals, eighteen revealed initial multiplicity.

Kaufman [4] mentions a contribution of Kocher's on the simultaneous primary occurrence of ovarian, breast and axillary cancer. Simultaneous primary cancerous disease of the tongue and the jejunum was observed by Abesser;[5] of the larynx and the thyroid by Tixier;[6] and of the stomach and the uterus by Reutter.[7] Simultaneous, primary sarcoma of the gall-bladder and the uterus is described by Schmincke.[8]

Jacob Wolff, in his book, "Lehre von der Krebskrankheit," says:

The development of several primary carcinomas of the same structure and within the same organ is intimately connected with the question of whether the carcinoma develops monocentrically or multicentrically, a problem which today is not entirely solved.

According to von Hansemann,[9] both forms of development are possible. Therefore, it may be that from multiple minute foci, from which usually a single carcinoma is formed, several independent, primary tumors may occasionally develop. Von Hansemann [10] observed multiple primary carcinoma in the stomach. Glenk [11] made a similar observation. Three primary facial carcinomas were described by Schimmelbusch [12] and multiple primary vulva carcinomas are mentioned by Fromme. [13]

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1. Gross: Cited by Williams, W. R.: Natural History of Cancer, New York, Wm. Wood & Co., 1908, p. 298.
2. Billroth: Cited by Williams (Footnote 1).
3. Nichols: Cited by Williams (Footnote 1).
4. Kaufman, C.: Virchows Arch. f. path. Anat. **75**:317, 1879.
5. Abesser: Cited in Michelson: Inaug-Diss., Zur Multipizitaet der primaeren Karzinomen, Berlin, 1889.
6. Tixier: Lyon méd., 1899, No. 22.
7. Reutter: Inaug.-Diss., Lausanne, 1902.
8. Schmincke, A.: Virchows Arch. f. path. Anat. **183**:160, 1906.
9. Von Hansemann: Ztschr. f. Krebsforsch. **1**:183, 1904.
10. Von Hansemann: Ztschr. f. Krebsforsch. **1**:195, 1904.
11. Glenk, K.: Inaug.-Diss., Erlangen, 1900.
12. Schimmelbusch, C.: Arch. f. klin. Chir. **39**:860, 1889.
13. Fromme: Hegar's Beitr. **9**:382, 1904-1905.

Besides this histogenetic explanation for the occurrence of multiple primary neoplastic disease in the same organ, there must be other etiologic factors, especially precancerous affections. Skin cancers that have this etiologic factor in common are regularly multiple; i. e., some form of inflammatory skin disease precedes their appearance.

"The multiple primary, widely separated carcinoma of the intestinal tract, in which the histogenetic explanation cannot be considered, can be traced back to the same causes."

Fig. 1.—Typical squamous-cell type epithelioma of the glans penis (slightly reduced from a high power magnification).

In the case of multiple primary carcinoma of the ileum observed by Lubarsch,[14] Walter[15] seeks the cause of the multiplicity in the tuberculous ulcers

14. Lubarsch: Virchows Arch. f. path. Anat. **111**:280, 1888.

15. Walter, M.: Inaug.-Diss., Rostock, 1896, p. 54; Arch. f. klin. Chir. **53**:1, 1896.

preceding, which brought about changes in the mucous membrane and prepared the soil for the cancerous disease.

A similar observation is communicated by Bunting,[16] Walter and Oberndorfer,[17] and by Notthafft,[18] who definitely observed the formation of the cancer tubules from the proliferating gland tubules.

Much stronger evidence for the diagnosis of multiple primary cancer is the fact that the individual tumors show a different histologic structure. A number of such cases have been reported.

Multiple primary sarcomas of different kinds and in different organs have also been described.

Following radical operation in cases of sarcoma, a recurrence in the form of carcinoma has been described.[19]

A case of simultaneously existing chorionepithelioma and primary gastric carcinoma has been reported by Davidsohn.[20]

Three primary malignant neoplasms of various types in different organs of one person have been described by Goetting.[21] They were a

Fig. 2.—Multiple primary epithelioma of the tongue: *A*, back of tongue lesion; *B*, tip of tongue lesion.

squamous-cell epithelioma of the larynx, an adenocarcinoma of the rectum and a medullary carcinoma of the stomach.

On the whole, these cases of multiple primary neoplasms in one person are not frequent, as is easily perceived from the following figures:

In 1,000 necropsies in cancer cases, von Hansemann found only five multiple primary cancers. Redlich,[22] in 507 cancer cases, found multiple primary cancer only twice.

16. Bunting: Bull. Johns Hopkins Hosp. **15**:389, 1904.
17. Oberndorfer: Beitr. z. path. Anat. u. z. allg. Path. **29**:516, 1901.
18. Notthafft, A.: Deutsch. Arch. f. klin. Med. **54**:555, 1894-1895.
19. Quoted by Wolff, J.: Lehre von der Krebskrankheit, p. 412.
20. Davidsohn, C.: Charité-Ann. **39**:426, 1905.
21. Goetting: Ztschr. f. Krebsforsch. **7**:675, 1909.
22. Redlich: Ztschr. f. Krebsforsch. **7**:675, 1909.

Feilchenfeld,[23] in 507 necropsies in cancer cases, found it only ten times; and Riechelmann,[24] in 711 necropsies, only twice.

The researches of Hauser and Petersen [25] into the structure of small cancerous nodules, by means of serial sections and reconstruction models, showed that the disease spreads multicentrically, each ingrowing column being an outgrowth from the original germ, and, therefore, at

Fig. 3.—Multiple epithelioma of tongue: cervical lymph gland metastasis, showing the presence of squamous-cell type epithelioma with pearl formation.

23. Feilchenfeld: Beitr. z. Statistik u. Kasuistik d. Karzinoms, Inaug.-Diss., Leipzig, 1901.

24. Riechelmann: Eine Krebs statistik vom path. Anat. Standpunkt, Inaug.-Diss., Rostock, 1902.

25. Hauser and Petersen: Cited by Williams (Footnote 1).

first, continuous with it. The modern conception is that the disease springs up, as a rule, from a single original germ; exceptionally, from more than one, and this latter condition constitutes primary multiplicity.

It should be remembered in this connection that all benign neoplasms are frequently multiple in origin; uterine myomas, for instance, frequently occurring as multiple primary tumors.

Fig. 4.—Squamous-cell epithelioma of tip of tongue (slightly reduced from a low power magnification).

Williams [26] states:

Of the many cases reported recently the most striking are those in which the tumours arise concurrently in both of paired organs, or in both of other

26. Williams, W. R.: Natural History of Cancer, New York, Wm. Wood & Co., 1908.

bilaterally symmetrical parts of the body. The chief local varieties occur in the breast. The great majority of these cases are, however, due to direct extension of the primary disease, or to its dissemination. Occasionally it springs up independently in the opposite breast.

Usually the anatomical structure of these bilateral tumours is similar, occasionally they are of different anatomical build, as the scirrhus of one breast and sarcoma of the other breast described by DeMorgan, Czerny, Bryant and

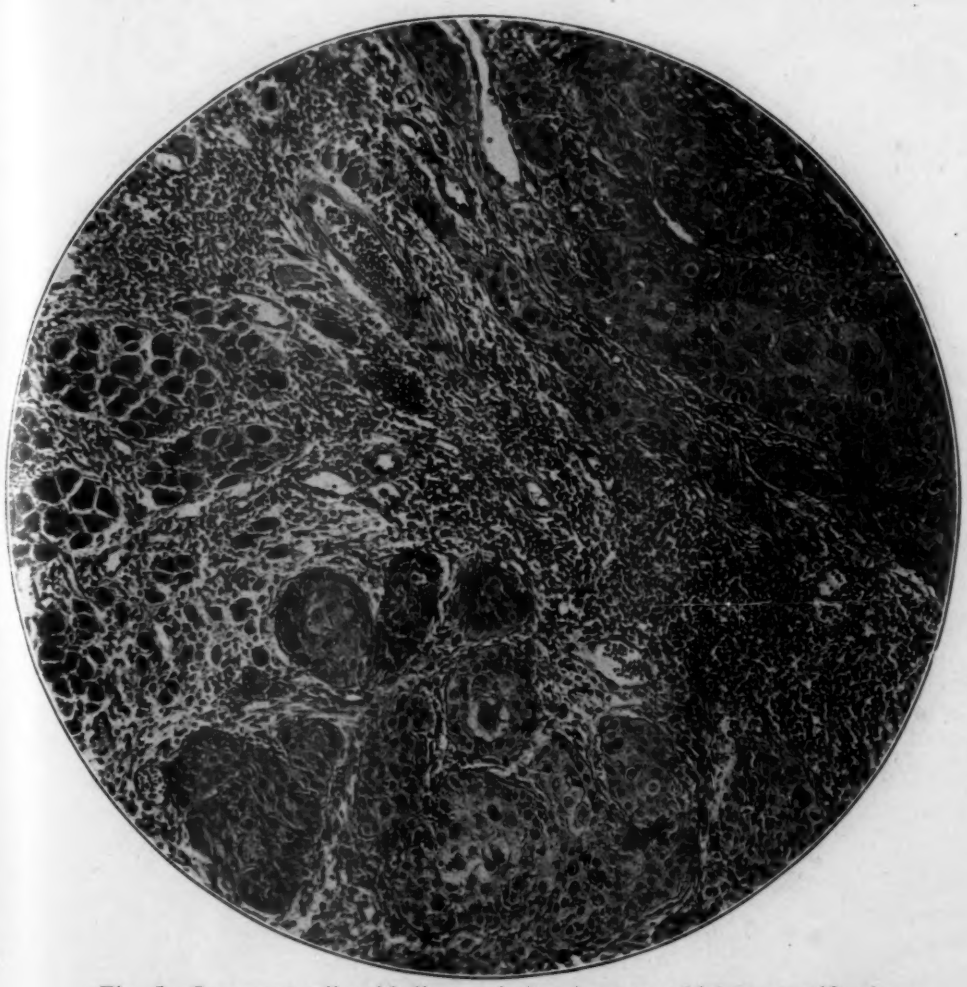

Fig. 5.—Squamous-cell epithelioma of tip of tongue; higher magnification (slightly reduced), showing invasion of musculature by the cancer cells.

Billroth. The ovaries, testes, kidneys, adrenals, eyes, ears, extremities, skin (most frequent), gastro-intestinal tract (next in frequency) and the uterus figure most prominently in the literature.

Triple epidermoidal cancer of the tongue is reported by Hayward and Henderson,[27] epidermoidal cancer of the tongue, with double cancer

27. Hayward and Henderson: Lancet **2**:22, 1901.

of the esophagus, by Bucher,[28] and epidermoid cancer of the tongue with columnar cell (colloid) cancer of the jejunum by Abesser.[29]

The conclusions reached on this subject by Williams are:

1. The fact of the occurrence of multiple outbreaks of malignant disease is thus clearly established, both for individual organs, for paired organs and for different parts of the body.

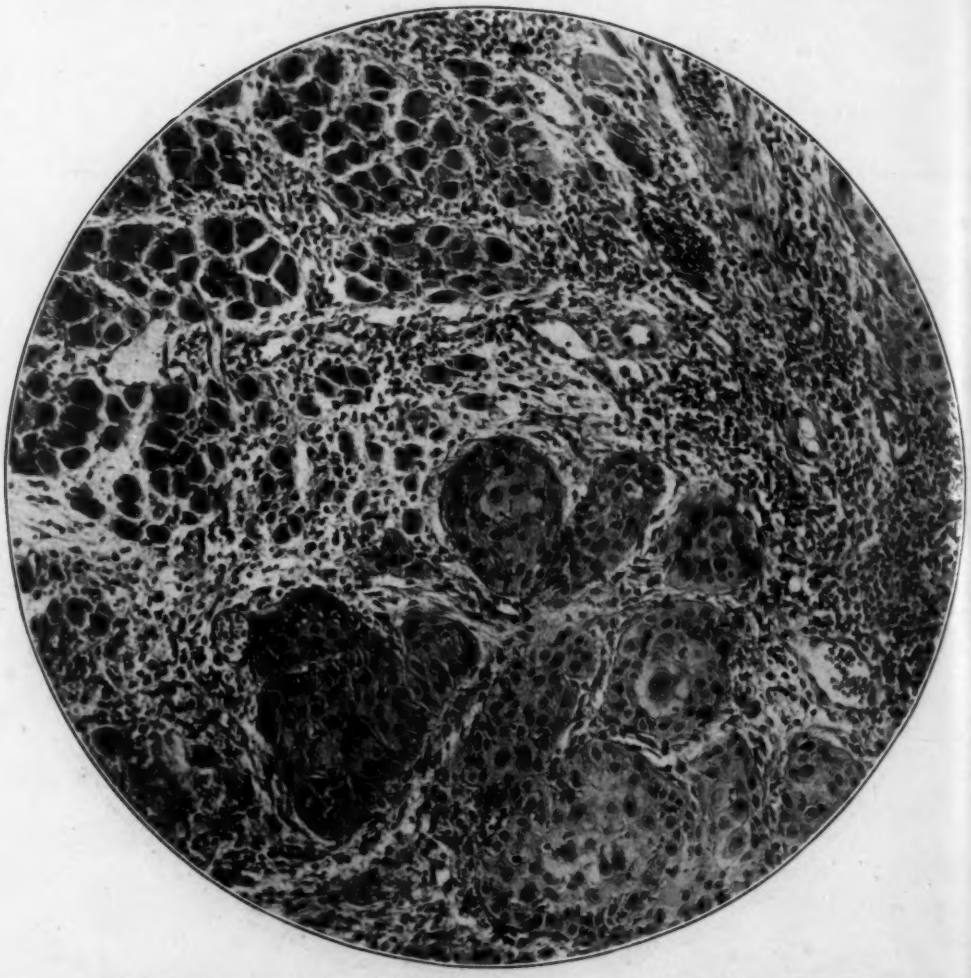

Fig. 6.—Squamous-cell epithelioma of tip of tongue (slightly reduced from a high power magnification).

2. It is further established that although primary multiple malignant tumours are generally of the same kind, yet, in many instances, they are generically different (epithelioma and sarcoma); and even when the multiple growths are

28. Bucher, R.: Beitr. z. path. Anat. u. z. allg. Path. **14**:71, 1893.
29. Abesser: Inaug.-Diss., Berlin, 1887.

of the same genus (e. g., epithelioma) they may be of different varieties (e. g., colloid cancer of one breast and scirrhus of the other, etc.).

3. Multiple occurrence of malignant disease is probably less exceptional than is generally believed, especially in the case of paired organs.

4. Initial multiplicity is relatively often concomitant with certain structural derangements, which may be assumed to give predisposition thereto. These derangements comprise prenatal developmental irregularities, especially obvious

Fig. 7.—Squamous-cell epithelioma of back of tongue, showing typical morphology.

in early life, bilateral forms of multiplicity; local hyperplastic lesions, such as chronic seborrhoea, chronic eczema, lupus, and the effects of various irritants, such as soot, tar, paraffin, etc., especially obvious in cutaneous manifestations; in the gastro-intestinal system, such lesions as multiple polypi; and, in the breast, the puerperal state. In the uterus, conditions of this kind are less obvious; but they may nevertheless exist.

5. Taken in their entirety, these various considerations point to some general systemic change as the predisposing cause of primary multiplicity.

In this connection, one might add that primary multiplicity is a clear evidence of the predisposition of an organ, even an individual predisposition (in primary multiplicity of different organs), to cancer development; also that the primary multiplicity in different organs is an effective argument against the Cohnheim theory of cancer development from embryonal rests.

Renaud [30] recently reported an ulcus rodens of one temple, which developed in the course of five or six years on a patch of senile keratosis. A carcinoma developed shortly thereafter on the other temple. The neoplasms were of different structure. He asks why multiple cancer is so rare. None of the prevailing cancer theories seem to throw any light on this question, in his opinion.

Bertocchi [31] recently published the case of a man, aged 29, who had an angiosarcoma of thigh and an epithelioma in the eye. He compares this case with thirty-four analogous cases of dissimilar malignant tumors on record, besides thirteen in which the cancers were of similar structure at remote points in the digestive or sexual system. He gives also a long list of cancers of similar structure in organs of different systems, in two symmetrical organs or at different points in the same organ. He cites the literature on cancer of the skin following lupus, roentgen-ray therapy, senile seborrhea, etc., and discusses the theories as to the etiology.

In the same year (1921) DeWitt Stetten [32] added to the literature a case of multiple simultaneous tumors of different anatomic structure —a metastasizing hepatoma (liver-cell adenoma) and, simultaneously, a typical epithelioma of the esophagus. He concludes with the suggestion that this patient exhibited a distinct tumor diathesis.

REPORT OF CASE

An American, postmaster and owner of a cigar factory, aged 62, had enjoyed ordinary good health until about 1918, when he noticed an irritated condition of the tongue. His physician told him the lesion was harmless; prescribed a mouth wash, and advised against excessive smoking, to which the patient was addicted, using both pipe and cigars, as many as from twenty to twenty-five of the latter a day. He also had dirty teeth with ragged and sharp edges, for the care of which he was sent to a dentist. The tongue lesions healed up within a short time, and he returned to his habit of excessive smoking and neglected to have his teeth attended to.

In 1922, he noticed a lesion on the penis, which proved to be a typical squamous-cell type epithelioma (Fig. 1). Amputation of the penis was per-

30. Renaud, A.: Rev. méd. de la Suisse Rom. **41**:773-782, 1921.
31. Bertocchi, A.: Policlinico (sez. chir.) **29**:361 (July) 1922.
32. Stetten, De Witt: Proc. New York Path. Soc. **21**:42, 1921.

formed, and as there were no suspiciously enlarged inguinal glands or other evidence of metastasis, nothing further was done at the time.

About a year later, the patient noticed "blisters" on his tongue, but considered it a recurrence of the condition of a few years before. A visit to the physician who had treated the tongue lesion five years ago confirmed his view that it was an irritation due to excessive smoking and so valuable time was lost with gargles and washes. The local condition became more annoying, interfering with both speech and eating, and a considerable amount of local pain was experienced. These symptoms brought the patient to New York where the surgeon who had amputated the penis immediately recognized the lesions as epithelioma of the tongue. As he had had bad results with straight surgery in these cases and as the son-in-law of the patient, a physician, opposed a mutilating operation, the application of radium was decided on. The patient was sent to a competent roentgenologist who owned some radium. The method employed, as described in a letter, speaks volumes for the education needed by many men using radium therapeutically. To quote from the letter: "I used an application of a ten milligram plaque for four hours, filtered through 0.1 mm. of aluminum."

I saw the patient two weeks after this treatment. There was no change in the lesions except that the pain was more severe.

The tongue had at its tip, and somewhat to the right, an ulcerated lesion, 2 cm. by 3 cm., with a very hard raised edge (Fig. 2 *b*). Separated from this by about 2.5 cm. of apparently normal tongue tissue was a second lesion, at the right margin and back of the tongue, 3 cm. by 4 cm., elliptical in shape and bounded by a very hard raised edge (Fig. 2 *a*). There were a number of jagged and dirty teeth in the mouth.

The man, though of spare frame, had not lost any weight during the past year and his appearance did not suggest cachexia. The penis stump looked healthy and normal. No glands could be palpated in the inguinal region or in the neck. The heart sounds were normal. The blood pressure was 135 systolic, 90 diastolic, but the chest gave evidence of a chronic bronchitis, which was said to have existed for many years.

It was decided to treat the local lesions with radium emanations in bare tubes and to ligate the vessels of the corresponding side of the neck. By means of a 1 per cent. procain epinephrin infiltration anesthesia, the right external carotid and its lingual and superior thyroid branches were ligated. In the course of the dissection of the parts, a small lymphatic gland at the bifurcation of the common carotid, suspicious because of its hardness, was removed. The microscopic examination disclosed that it contained typical epidermoid cancer (Fig. 3).

After carefully and thoroughly plugging off the pharynx with gauze, and with a painstakingly conducted ether anesthesia, under negative pressure, a wedge-shaped piece of tissue was removed from each of the two tongue lesions. The microscopic examination of the two specimens (Figs. 4, 5, 6 and 7) showed that they contained characteristic squamous-cell epithelioma with scant pearl formation. The infiltration of the cancer cells extended into the musculature, and not only were the two specimens from the tongue similar in histologic structure but they, together with the lymphatic gland removed from the neck and the penile neoplasm removed one year before, showed a morphologic structure, so strikingly similar that, without labeling, it would be impossible to tell which was which.

The little defects caused by the biopsies were repaired with sutures.

The radium emanations, averaging 1.06 millicuries to each bare tube, were then implanted in the lesions, eight bare tubes in the lesion at the tip of the tongue and twelve in the one on the back of the tongue; the lesion at the tip receiving 1,082 and the lesion at back margin 1,623 millicurie hours, a total of 2,705. These figures were arrived at after subtracting 2 per cent. for destruction taking place between the time of collection and the time when the tubes were buried in the tissues.

The immediate effects were satisfactory, the neoplasms sloughing out and leaving a healthy granulating margin.

In spite of the ligation of the neck vessels, there were two rather alarming hemorrhages from the lesion at the tip of the tongue, evidently due to anastomosis of the vessels on the unligated side, the first one after ten days and the second one after twenty-one days. Both were controlled by local pressure.

Unfortunately, the patient succumbed to a lung abscess, one of the common terminations of cancer of the tongue, five weeks after the radium implantation. A thorough irradiation of the neck with roentgen rays had been contemplated.

This case is reported to add to the literature another instance of primary multiple outbreak of malignant disease, not only in an individual organ but also in different parts of the body, with a comparatively long interval between the occurrence of two of the lesions.

The case may serve, for those so inclined, as a source of speculation on predisposition of each organ and individual predisposition to the "systemic" disease of cancer.

BONE GROWTH IN TRANSPLANTED BONE*

AN EXPERIMENTAL STUDY

LEONARD W. ELY, M.D.
SAN FRANCISCO

When a piece of bone is removed from an animal by an aseptic operation and is immediately buried in the tissues of the animal, new bone formation takes place in it. All authorities agree on this point. Does the transplanted bone die, and simply by its presence stimulate the surrounding tissues to form new bone in it, or, after the manner of a graft from a tree, does it survive, and itself form the new bone? This apparently simple question has been the occasion for a great amount of investigation, but has not yet been definitely answered. The weight of experimental evidence is on the side of the first hypothesis; circumstantial evidence is on the side of the second, and considerable experimental evidence also.

There are two main difficulties in our way: 1. It is not always possible to distinguish dead bone from living. 2. We are uncertain of our identification of the osteoblast, as well as of its source. To these difficulties has been added a third in the failure of certain writers to distinguish between the osteoblast and the bone cell.

Now, we must never lose sight of the fact that the interpretation of things seen under the microscope is a personal matter, and even authorities may differ. With this apology I may state that after considerable investigation I reached the conclusion that the transplanted bone died, and that all succeeding changes in it were caused by the blood vessels which pushed into it from the surrounding tissues.[1] Haas,[2] one of the stoutest modern advocates of the viability of the transplant, has pushed the theory to what I consider its logical absurdity. He kept sterile bone for from two to five days before imbedding it in the animal from which it was taken. Some of it he kept in the icebox. As the result of his investigation, he concluded that the transplanted bone survived, and that

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*From the laboratory of surgical pathology of the Stanford University Medical School.

1. Ely, L. W., and Cowan, J. F.: A Study of Buried Bone, J. Orthop. Surg. **1**:100-108 (Feb.) 1919. Ely, L. W.: An Experimental Study of Buried Bone, Ann. Surg. **70**:747 (Dec.) 1919; the Formation of Bone, Ann. Surg. **69**:225 (March) 1919; Experimental Study of Healing of Fracture, Arch. Surg. **5**:527 (Nov.) 1922; Inflammation in Bones and Joints, Philadelphia, J. B. Lippincott Company, 1923.

2. Haas, S. L.: Further Observations on the Survival of Bone After Removal from the Body, Arch. Surg., *to be published*.

the activity of the fragments kept in the icebox was greater than that of those kept at room temperature. Dr. Haas courteously permitted me to study his material; and I reached the conclusion that the bone in every instance had died, and that new bone was being built on the old through the activity of the blood vessels which had pushed into the fragment from the surrounding tissues. This view is reinforced by what we see around us every day. If, outside a laboratory, a piece of meat or a piece of bone were kept in an icebox, at freezing temperature, it would be hard to convince ourselves that it was alive, and could be the seat of active regeneration. Otherwise, an effective treatment has been

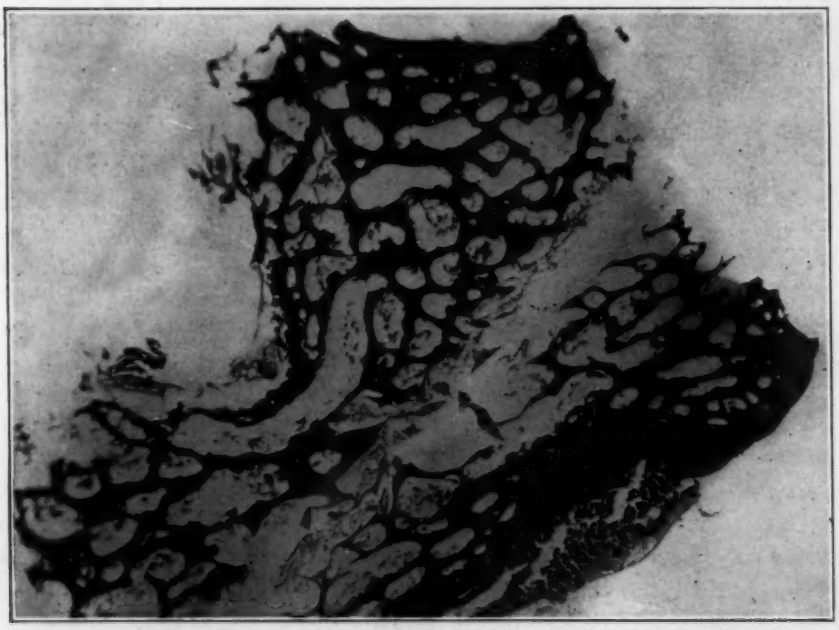

Fig. 1.—Part of fragment of bone from Cat 36. The beginning of the breaking up of the marrow can be seen.

discovered for frozen fingers, which can easily be demonstrated clinically. I doubt if even the most enthusiastic advocate of this theory would be willing to make a personal demonstration of it.

In most of the experimental work on buried bone, the fragment has been buried for a considerable time. In my two previous series, the experiments lasted from 14 to 1,103 days, very few for less than three months and the majority for about a year or more. They served well to show what finally happened to the fragment, but I thought that experiments lasting but a few days would prove more competent in determining whether the fragment lived or died. Changes which take

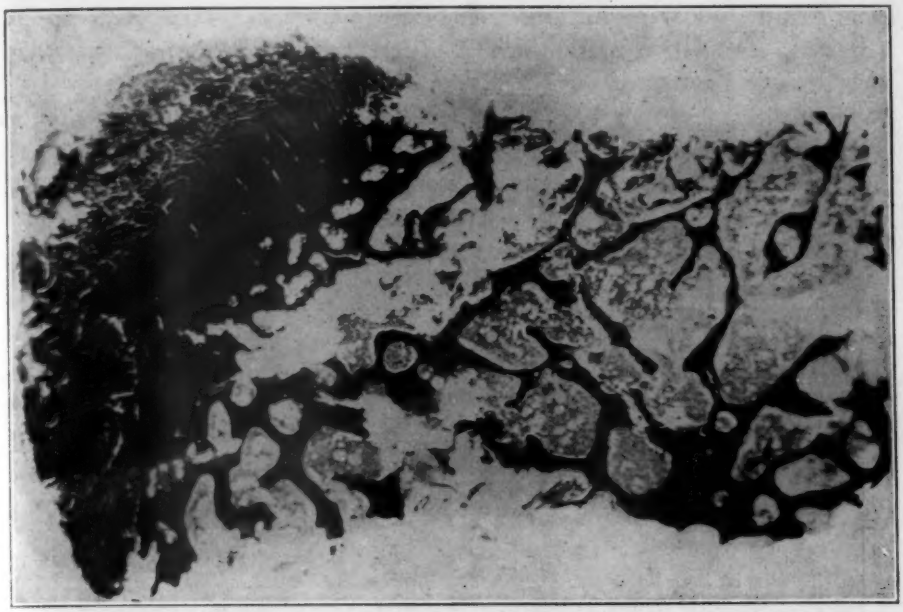

Fig. 2.—Part of fragment from Cat 37. Attachment of the ligament at the left.

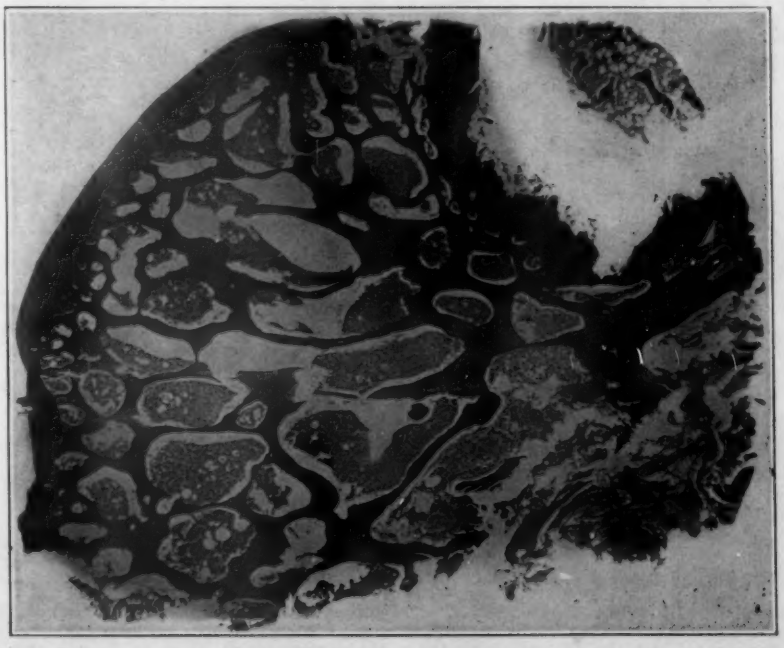

Fig. 3.—Section of fragment from Cat 38. The marrow has lost its reticulum, and for the most part is separated from the trabeculae. It is dead. The cartilage, on the left, is in a good state of preservation.

place in a bone fragment after blood vessels from the surrounding tissues have entered it are capable of different interpretation, according, perhaps, to the bias of the observer; but any signs of activity observed within the fragment a few days after embedding would naturally rule out the surrounding tissues as the active factor in bone regeneration.

One other aspect of the problem deserves mention. In our experiments on the viability of transplanted tissues, it is necessary to bear in mind the essential rôle played by the size of the fragment of tissue. It

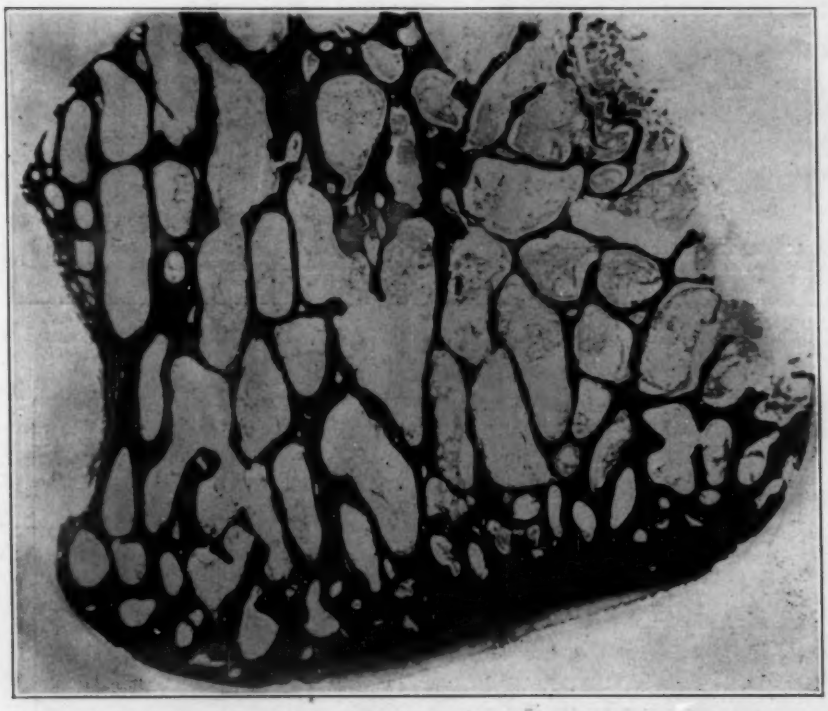

Fig. 4.—Section of fragment from Cat 39. Cartilage below. The marrow is breaking up.

is quite possible that almost any tissue may live for a few minutes after removal. If a minute fragment of bone, for instance, were used for transplantation, and were immediately buried in the muscle of the animal from which it was removed, it might be nourished by the body fluids, and might never die; but this is not the point at issue. The question we are trying to decide is whether a macroscopic piece of bone, of a size comparable with that of a piece adapable to bone graft work, lives or dies. Is there any activity in the center of such a bone fragment before the blood vessels push into it from the surrounding tissues?

To determine this is the object of this series of experiments. It is, as I have said, not always possible to say whether the bone is alive or dead. I have usually found the condition of the contained marrow to be the best criterion on this point.

The illustrations are photomicrographs of the stained slides of sections of the buried bone fragments, taken with a 3-inch objective. Naturally, they cannot show finer detail, but they do show the empty marrow space, so to speak, and especially the empty zone immediately adjacent to the trabeculae.

Fig. 5.—Part of fragment from Cat 44. The marrow reticulum is gone.

EXPERIMENTAL DATA

Cats were anesthetized with ether, the skin in the region of the thigh and knee was shaved, and disinfected with iodin. The knee joint was opened through a lateral incision, and a piece of the lateral condyle was removed, and was immediately buried in the thigh muscles. When the animal was killed, the bone fragment was removed, fixed in liquor formaldehydi; then in alcohol, and was then decalcified in 5 per cent. nitric acid. After dehydration, the fragment was mounted in paraffin, cut with a microtome, and stained with hematoxylin and eosin, and with the van Gieson stain.

Cat 36 (four days).—An incision was made over the lateral aspect of the knee joint and thigh, the capsule was opened and part of the lateral ligament

of the knee was divided. Practically the entire lateral condyle was removed with a Liston forceps, and was buried deep in the quadriceps muscle. The wound was sewed up with two layers of catgut, and was dressed with collodion. The cat died four days after the operation of an unknown disease. The wound was healing, and presented no sign of infection. The bone fragment was found under the quadriceps muscle without any visible reaction in the surrounding tissues.

Histology.—The cartilage cells stained poorly, and the surface of the cartilage was roughened. Some of the bone cells still stained; many were broken up. Many of the lacunae were empty. Most of the marrow was necrotic. The bone substance itself was evidently degenerating. There was no evidence of the vascularization of the marrow.

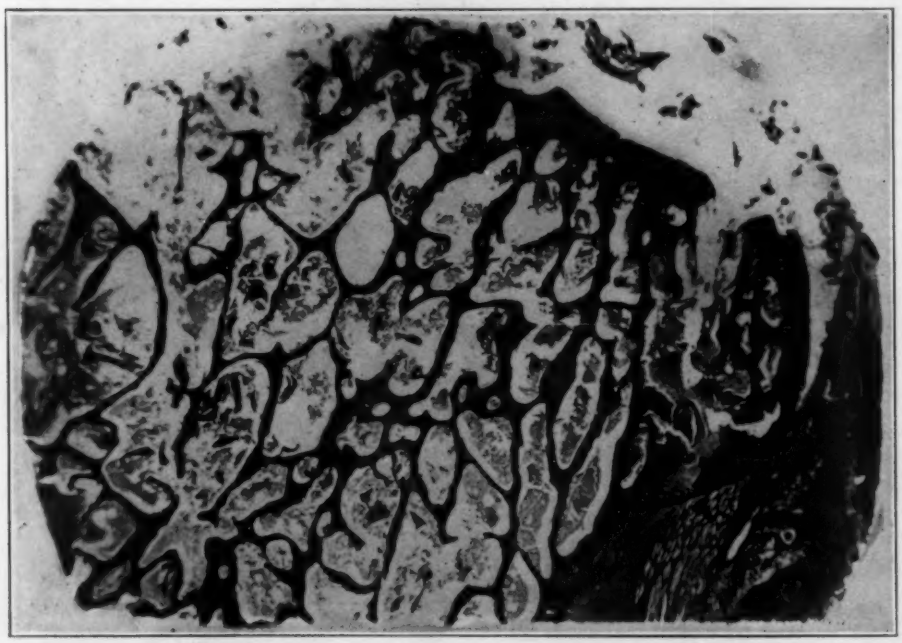

Fig. 6.—Part of fragment from Cat 45; dead bone and marrow. Vascularization of the marrow has begun, at the periphery.

Outcome.—Death of the fragment occurred.

CAT 37 (four days).—The procedure was as with Cat 36. The animal died four days after the operation of an unknown disease. The wound was healing without sign of infection. The bone fragment was found buried in the thigh muscles, without evidence of inflammatory reaction.

Histology.—The fragment was small, about 2.5 by 9 mm., with cartilage on one short side. The cartilage was fibrous, and seemed continuous with the imbedding tissue. The marrow reticulum was broken up. Its cells stained poorly. The bone was dead, and its lacunae were empty for the most part. A few lacunae contained shrunken cells which stained deeply.

Outcome.—Death of the fragment occurred.

CAT 38 (thirteen days).—The cat died, thirteen days after operation, of an unknown disease. The wound was healed, without sign of infection. The fragment was found snugly buried in the muscle without inflammatory reaction around it.

Histology.—The marrow had lost its reticulum. The marrow cells were evidently dead. Their nuclei did not stain. The bone lacunae were empty. The bone was evidently dead. The cartilage was in a good state of preservation.

Outcome.—Death of the fragment occurred.

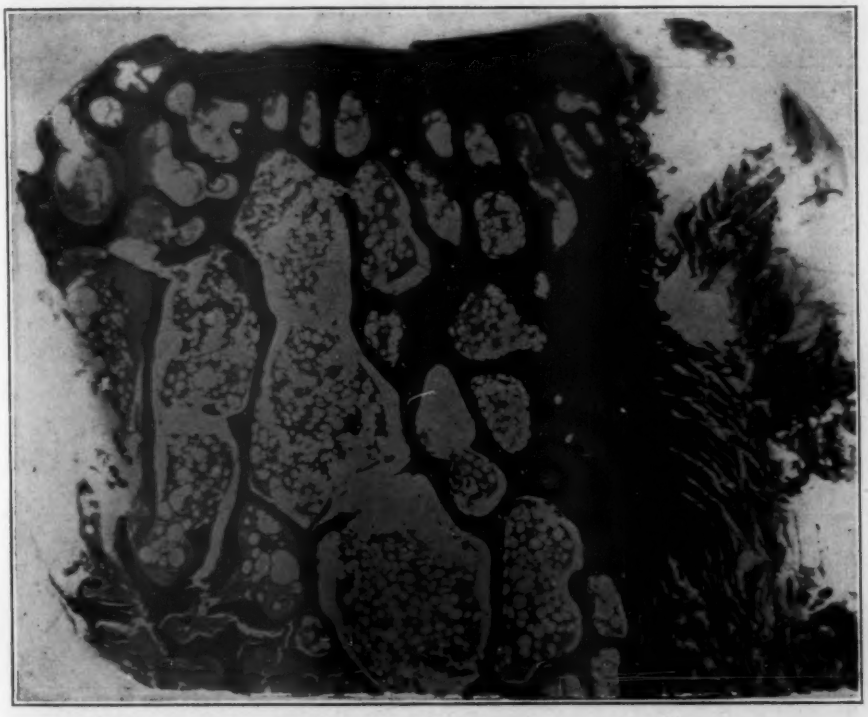

Fig. 7.—Part of fragment from Cat 46. Death of bone and marrow, and breaking up of the marrow reticulum. In this slide under higher power, vascularization with new bone and marrow formation can be seen in places at the periphery.

CAT 39 (eight days).—The procedure was as before. The cat died eight days after operation. To external appearances, the wound was all right, but, when it was opened, the bone fragment was found lying loose in a collection of pus.

Histology.—The reticulum of the marrow was gone, and the marrow tissue was irregular and fragmentary. The marrow cells stained poorly, and were evidently dead. The bone tissue stained poorly. Many of its lacunae were empty, but some bone cells stained in their lacunae. The cartilage was breaking up at its surface, and its cells stained poorly.

Outcome.—Death of the fragment occurred. It should be noted that, whereas in the face of suppuration, the fragment was certainly dead; nevertheless some of the bone cells stained fairly sharply.

CATS 40, 41, 42, 43.—Infection took place in the operative wound, and the material was discarded as being useless for this investigation.

CAT 44 (three days).—The procedure was as before. The cat died three days after operation. It was in very poor condition when the operation was performed. There was no sign of infection about the wound.

Histology.—The reticulum of the marrow was gone, and the marrow cells stained poorly. No blood supply to the marrow could be seen. The bone

Fig. 8.—Part of fragment from Cat 47. The cartilage is in a good state of preservation, but the bone and marrow are probably dead.

matrix stained poorly. Many of the bone lacunae were empty. The cells in the rest were shrunken. The cartilage was fairly well preserved.

Outcome.—Death of the fragment occurred.

CAT 45 (eight days).—The procedure was as before. The cat was killed eight days after the operation. Superficial infection of the wound had taken place, but evidently the infection had not spread into the deep part of the wound, and the transplant was not involved.

Histology.—The bone and marrow were manifestly dead. Here and there, at the periphery of the fragment, there was a little live marrow, and vascularization of the fragment evidently had begun from the surrounding tissue. The cartilage was degenerate.

Outcome.—Death of the fragment occurred. Vascularization had begun from the surrounding tissue.

CAT 46 (ten days).—The procedure was as before, except that instead of one long incision over the lateral aspect of the thigh and knee, two incisions were made, one over the knee for removal of the bone, and another over the thigh for burying it.

The cat was killed ten days after operation. No infection had taken place about the wound.

Histology.—The section examined was 4 by 8 by 9 mm., triangular in shape, with cartilage on the short side. The marrow reticulum was broken up in most of the section, and the marrow and bone were evidently dead. On the

Fig. 9.—Part of fragment from Cat 48. Death of bone and marrow, except at a few places at the periphery, where vascularization and vitalization have begun.

sides composed of rough, open meshed bone, vascularization had begun from the imbedding tissue, and here the marrow was fibrous, alive, and possessed a reticulum. Here, at the circumference, in these areas of living tissue, bone formation had begun on the margins of the trabeculae. The cartilage was in a fair state of preservation.

Outcome.—Death of the fragment occurred. Vascularization and bone formation had begun at the periphery.

CAT 47 (six days).—The procedure was that followed with Cat 46. The cat was killed six days after operation. The wounds were open and infected, the infection extending down to the femur in the distal wound; that is, in the wound over the knee joint. In the proximal wound, it had extended only

part way to the transplanted bone, which was found encased in healthy muscular tissue. The infection evidently began superficially.

Histology.—The bone stained poorly, and was probably dead. Many of the lacunae were empty; in the others, the cells were shrunken. The marrow cells stained, but not sharply. Many of them were dead. The cartilage, as usual, was in a good state of preservation.

Outcome.—Death of the fragment occurred.

This specimen is evidence of the truth of the statement as to the difficulty of determining whether the bone fragment is really alive or dead. The stained slides were submitted to Professors Ophüls and

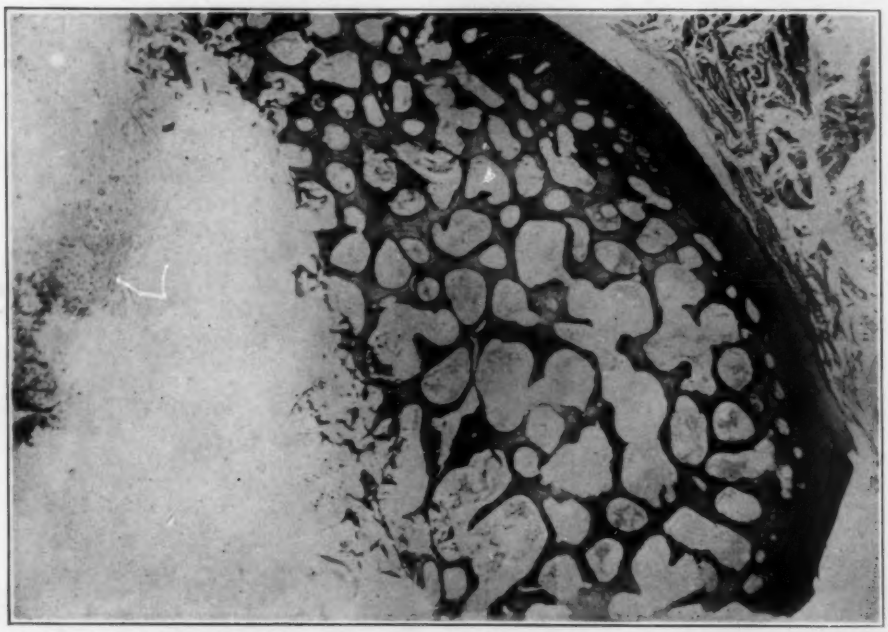

Fig. 10.—Part of fragment from Cat 49. Death of bone and marrow. Vascularization of the marrow has begun at a few places at the periphery.

Oliver for an opinion. They thought the bone was dead, but would not venture a positive statement.

Cat 48 (eleven days).—The procedure was that followed with Cats 46 and 47. The cat was killed eleven days after operation. Some superficial infection of the wound had occurred, but none beneath the deep fascia. No infection about the bone fragment was noted.

Histology.—Although a few of their shrunken cells stained poorly, the bone and cartilage were manifestly dead. Many of their cells had degenerated. Many of the bone lacunae were empty. The marrow was dead, except at a few places at the periphery of the specimen, where vascularization was beginning. Here, there was a little live fibrous marrow.

Outcome.—Death of the fragment occurred. Vascularization and vitalization of the marrow had begun at its periphery.

CAT 49 (nine days).—The procedure was that followed with Cats 46, 47, and 48. The cat was killed nine days after operation. The wound was almost healed, and showed no sign of infection.

Histology.—The cartilage cells stained, though not very well. The bone was dead; the marrow, for the most part was also dead, but here and there at the periphery of the fragment vascularization of the marrow had begun, and the marrow consisted of delicate, live fibrous tissue. There was no sign whatever of any new bone formation.

Outcome.—Death of the fragment occurred, with vascularization from the outside, beginning in the marrow.

CONCLUSION

When a piece of bone is removed, and is immediately buried in the soft tissues of the animal from which it has been taken, the bone and its contained marrow die. About a week afterward, vascularization of the bone marrow begins, and shortly thereafter, bone formation.

ENTEROCYST OF THE ILEUM, CAUSING OBSTRUCTION *

PAUL W. ASCHNER, M.D.
Adjunct Surgeon and Assistant in Surgical Pathology, Mount Sinai Hospital
NEW YORK

Benign tumors of the small intestine are among the rare causes of intestinal obstruction. When they produce obstruction, they almost always do so by acting as the starting point of an intussusception. Exceptionally, they may cause obstruction by actual obturation of the bowel. The following case history is one in which obturation was effected by a cyst of the terminal ileum, occluding the ileocecal valve.

REPCRT OF CASES

History.—F. P., a girl, aged 6 months, admitted, Sept. 15, 1923, had been delivered normally at full term. She had been bottle fed after the first two weeks, and had required frequent changes in the formula. Twenty-four hours before admission, she began to vomit, first bringing up curdled milk, and then clear fluid. She vomited eight times that day. The bowels did not move and enemas were ineffectual. When she was examined by rectum in the admitting room, a small greenish yellow stool was passed. There was no fever and no leukocytosis.

Physical Examination.—The child did not appear very ill. The abdomen was soft and slightly distended. On the right side, at the level of the iliac crest, there was a mass about 3 by 2.5 cm., smooth, ovoid and somewhat movable. It could just be reached by rectal examination. No peristaltic waves were observed.

Diagnosis.—Intussusception did not seem likely because there had been no tarry stools, and the bowel movement in the admitting room had been free from blood. The mass, moreover, did not appear tender. Twisted ovarian cyst was excluded because the mass was not sufficiently movable, had no apparent pelvic connection and was not tender. There was no fever, leukocytosis nor peritonitic signs. Ectopic kidney was considered, but the mass was longer in its transverse than in its longitudinal diameter. As no definite diagnosis was made, and as the bowels had just moved and the general and local findings indicated no emergency, it was decided to await further observation.

About six hours after admission, some increase of distention was noted. Ten hours after admission, peristaltic waves were observed and laparotomy for intestinal obstruction was decided on. The nature of the lesion was in doubt, intussusception seeming the most probable.

Operation.—Under ether anesthesia, a 3 inch (7.5 cm.) right rectus incision was made. Distended coils of small intestine presented. The mass was found to be in the ileocecal region and was easily delivered. A firm ovoid tumor

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* From the surgical service of Dr. Beer, and the Pathological Laboratory, Mount Sinai Hospital.

occupied the ileocecal junction, a small protrusion from it presenting between the leaves of the mesentery (Fig. 1). I believed that I was dealing with a myoma or fibroma of the intestine which obturated it completely. Because of the patient's age, primary resection was deemed inadvisable. A Witzel type enterostomy was performed about 6 inches (18 cm.) above the tumor, a large catheter being employed.

Outcome.—Although the enterostomy functioned well, vomiting recurred and the infant grew progressively weaker. The temperature mounted rapidly to 104.6 F. Death ensued about thirty hours after operation.

Necropsy.—There was congestion at the bases of both lungs. A localized plastic exudate was present about the site of the enterostomy. When the terminal ileum was opened along its free border, the obstructing tumor was found projecting into the orifice of the ileocecal valve (Fig. 2). It was covered by intestinal mucous membrane, and felt tense but elastic. When it was incised, a clear mucoid fluid was evacuated from a smooth walled cyst situated in the wall of the intestine, in the mesenteric part of its circumference.

Microscopic Examination.—Sections made through the serosal side of the cyst wall in the longitudinal direction of the ileum (Fig. 3) showed four distinct coats from without inward, namely serosa, muscularis (external longitudinal, internal circular fibers), submucosa and mucosa. The mucosa consisted of well developed muscularis mucosae, stroma, mucous glands and surface epithelium. Where the mucosa was well preserved and of some thickness, the surface epithelium was of simple columnar type with mucous glands dipping down into the stroma (corresponding to the crypts of Lieberkühn). In other areas, the mucosa was thin and no glands were present, and here the surface epithelium was of cuboidal type. Other parts of the cyst wall showed complete absence of epithelium, due either to degeneration and desquamation, or to artefact.

A section made through the intestinal side of the cyst wall showed, from without inward, the following structures: intestinal mucosa, atrophic and without the usual villi, but with a well developed muscularis mucosae; a poorly defined submucosa; a well defined layer of musculature consisting of circular fibers (cut transversely); two additional less well defined and narrower layers of muscle fibers, the outer being longitudinally, the inner circularly, arranged, and, finally, the lining of the cyst, poorly preserved and consisting chiefly of fibrous connective tissue.

A section made through the cyst at its point of fusion with the intestinal wall proper (Fig. 4) showed the cyst as a structure included in the wall of the ileum, apparently not continuous with it in any of its coats. It was somewhat difficult to determine precisely the layers of the intestinal wall between which the cyst was situated, but from the study of a number of sections, it appeared to lie between the two muscular coats of the intestine.

The following reports of similar cysts have been found in the literature.

Fränkel (1882):[1] A child died eleven days after birth, of intestinal obstruction beginning on the third day. At necropsy, a cystic tumor 2.5 cm. in diameter was found at the ileocecal junction, between the muscle layers of the intestinal wall. It was apparent only after the bowel had been opened, and contained a thin mucoid fluid.

1. Fränkel: Virchows Arch. f. path. Anat. **87**:275, 1882.

Sainsbury (1887):[2] A girl, aged 11 years, died of typhoid fever. At necropsy, a cyst was found in the colon just above the ileocecal valve. It had a serous lining membrane and a muscularis mucosae. The author thought it had formed from an invagination of the peritoneum during the development of the valve, or was possibly a mucous retention cyst (enterocystoma).

Hüter (1896):[3] A boy, aged 10 days, died of gastroenteritis. At necropsy, a cyst the size of a cherry was found in the submucosa of the valve of Bauhin. It contained a meconium-like material, and its wall showed epithelium of high mucous cells, irregularly developed glands of Lieberkühn and a muscularis mucosae. A small nodule of similar structure was found in the mesentery.

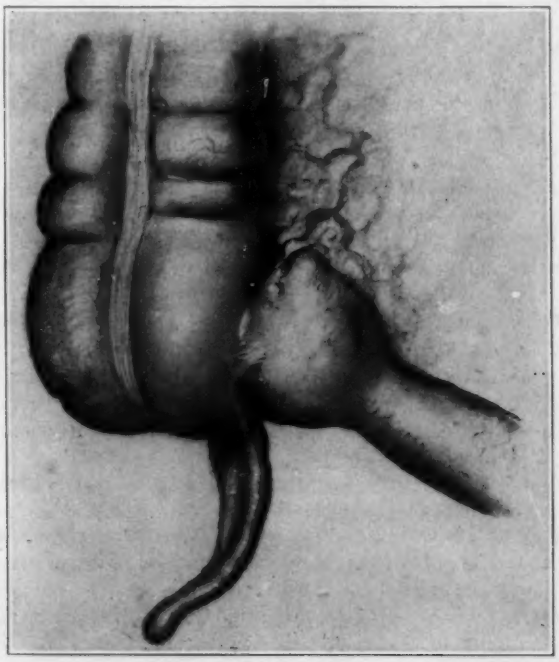

Fig. 1.—Appearance of tumor at operation.

Quensel (1898):[4] (*a*) A new-born infant died of asphyxia. At the ileocecal junction was a cyst about 3 cm. in diameter, arising from the anterior aspect of the ileum and encroaching on the lumen. It contained a clear albuminous fluid, and did not communicate with the bowel. The wall of the cyst showed from without inward, two layers of muscularis, submucosa and mucosa. The mucosa was thin and the epithelium only partly preserved. The lining cells were of high columnar type and here and there dipped down to form glands. From a careful study of the intrinsic musculature of the intestine and of the cyst wall proper, it was apparent that the cyst lay in the submucosa of the intestine.

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2. Sainsbury: Tr. Path. Soc. London **38**:146, 1887.
3. Hüter: Beitr. z. path. Anat. **19**:391, 1896.
4. Quensel: Nord. med. Ark. **9**:1, No. 30, 1898.

(*b*) A female infant, aged 4 months, died of bronchopneumonia. On the anterior aspect of the terminal ileum, close to the cecum, was a cyst 2.5 by 3.0 cm. It contained clear fluid and did not communicate with the intestinal lumen. The microscopic studies revealed the same structural relations as in the preceding instance, but the mucosa of the cyst was much richer in mucous glands and well preserved.

(*c*) A woman, aged 62, with intestinal obstruction, proved at operation to have a cystic tumor of the small intestine. The tumor was adherent in the pelvis and the loop of intestine was twisted. About 30 cm. of intestine, including the tumor, was resected. The patient died three days later of peritonitis, due to leakage. The tumor was situated opposite the mesenteric attachment of the bowel, and about 57 cm. above the ileo-cecal valve. On section, it presented a solid portion 3 cm. in diameter encroaching on the lumen of the intestine, and a cystic portion about 6 cm. in diameter. From the microscopic studies, the author concluded that he was dealing with a spindle-cell sarcoma arising from the submucosa of the bowel at the site of an enterocystoma. The secondary changes in the cyst due to hemorrhage and torsion had obliterated the evidences of a mucosal lining, but the muscle layers were still discernible.

(*d*) A specimen from the pathologic institute at Stockholm (1880) showed a subserosal cyst of the small intestine. It was situated opposite the mesenteric border, was 6 cm. in diameter and did not communicate with the bowel. The cyst was lined with a mucosa resembling that of the small intestine, and its wall consisted of submucosa and two muscle layers. The mucosa of the cyst, as well as of the intestine, showed many tuberculous ulcers.

Sprengel (1900):[5] A girl, aged 15, had had attacks of pain, vomiting and constipation since the age of 4. An indefinite mass lying transversely just above the umbilicus was palpated. At operation, an invagination of the cecum and ileum was found. Resection was sucessfully performed. The specimen presented a cyst 3 cm. in diameter in the mesenteric segment of the ileum at the valve of Bauhin. The cyst did not communicate with the intestinal lumen but showed a lining membrane similar to that of the small intestine.

Gfeller (1902):[6] A girl, aged 11 years, had been well until her fifth year. Recurrent attacks of colicky pain and vomiting came on at short intervals. A severe attack suggesting appendicitis or obstruction necessitated operation. A volvulus of the small intestine was found, due to a cyst, which was readily enucleated without entering the lumen of the bowel. It was apparently situated between the muscle coats of the intestinal wall. The cyst itself presented two muscle layers, submucosa and mucosa. The epithelium was of a transitional type, and there were no glands.

Krogius (1903):[7] A female infant, aged 2 months, suffered for two weeks with constipation. Vomiting, distention and visible peristalsis led to operation. A tumor was found in the terminal ileum opposite the mesenteric border. A two-stage operation was performed, but the child died of hemorrhage. The specimen showed a cyst the size of a pigeon's egg. Its wall showed a structure identical with that of the small intestine.

Ayer (1906):[8] A man, Japanese, aged 23, had a history of several attacks of constipation, vomiting and fever during the preceding seven years. The

5. Sprengel: Arch. f. klin. Chir. **61**:1032, 1900.
6. Gfeller: Deutsch. Ztschr. f. Chir. **65**:330, 1902.
7. Krogius: Ztschr. f. klin. Med. **49**:53, 1903.
8. Ayer: Am. J. M. Sc. **131**:89, 1906.

present attack was more severe, and recurrent appendicitis was diagnosed. At operation, a cyst of the cecum arising in its posterior attached wall was found. The anterior wall of the cecum was incised, and the cyst was incised and emptied. Its anterior wall, presenting in the bowel, was then removed and the cut edge whipped over with catgut. No microscopic examination was made. The patient recovered.

Turner and Tipping (1913):[9] An infant, aged 4 months, presented symptoms of intussusception, with a palpable mass. At operation, a cyst 2.5 cm. in diameter was found in the ileocecal angle between the leaves of the mesentery. As it

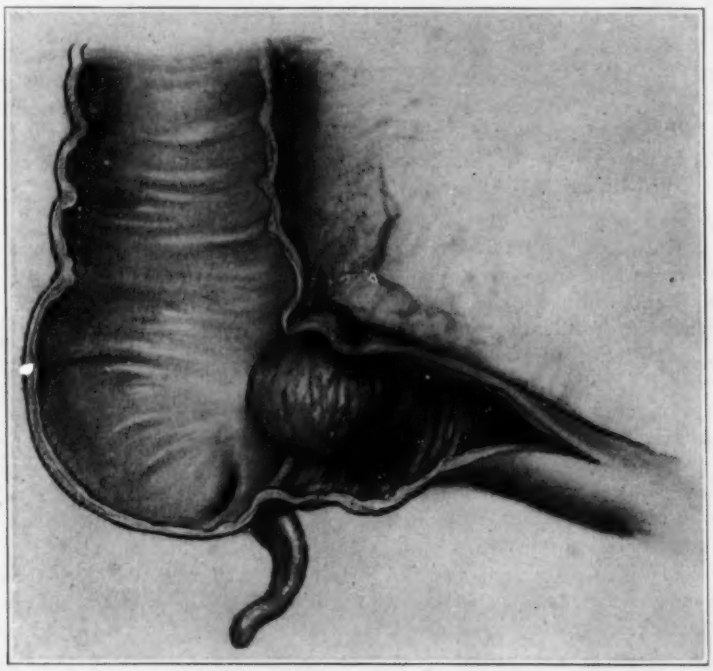

Fig. 2.—Appearance of cyst after intestine was opened.

could not be dissected out of the wall of the intestine, it was treated by marsupialization. The excised portion showed the structure of small intestine.

Blackader (1913):[10] A boy, aged 8 weeks, who had been well, began to vomit and lose weight. A mass was detected in the right iliac fossa and peristaltic waves appeared. At operation, the tumor was found in the cecum, and a resection was performed. The baby died on the twelfth day. The specimen showed a cyst in the wall of the cecum opposite to and obstructing the ileocecal valve. It was lined by columnar epithelium with few glands, and a submucosa. Between the mucosa of the cyst and of the intestine, three layers of muscle fibers could be distinguished.

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9. Turner and Tipping: Proc. Roy. Soc. Med. **7**:29, 1913.
10. Blackader: Tr. Am. Pediat. Soc. **25**:296, 1913.

Ball (1914):[11] A boy, aged 3 months, developed signs of intestinal obstruction. Because of a mass palpable in the right lower quadrant, intussusception was diagnosed. The ileocecal valve was found blocked by a cyst arising from the posterior and external wall of the cecum. Its contents were mucoid and it was lined by flattened epithelial cells. The child recovered after resection and ileostomy.

Bolton and Lawrence (1916):[12] A boy baby had vomited a little after feeding since birth. At 5 weeks, this became worse. There was vomiting, constipation, loss of weight and a mass in the right iliac fossa. Under observation, improvement was temporary, but death occurred two weeks later. At necropsy, a cyst, 2.5 by 3.0 cm. was found, at the ileocecal angle. The wall showed a structure resembling small intestine. The authors believed it arose from a diverticulum which had become shut off from the bowel.

Hanson (1917):[13] A cyst protruding through the ileocecal valve was situated between the layers of the intestinal musculature. Its lining showed few glands. The author believed pancreatic rests to be the origin of such cysts.

Spencer and Keith (1921):[14] A specimen from the Museum of the Royal College of Surgeons is depicted, resembling closely the one reported in this paper.

MacAuley (1923):[15] A girl, aged 6 months, presented the typical signs and symptoms of acute intussusception. At operation, diagnosis was confirmed, but the reduction was difficult, and a knoblike structure presented at the site of the ileocecal valve. Resection was performed but unsuccessfully. The specimen showed a thick walled cyst protruding through the valve into the cecum. It showed the structure of small intestine. Keith declared it of congenital and diverticular origin arising by outgrowth from the embryonic bowel.

Lotheisen (1923):[16] A girl, aged 21 years, had had pain in the right lower quadrant of the abdomen for one year. A cystic tumor was palpable in the right iliac fossa. At operation, a cyst was found in the cecum along its outer aspect. As it could not be shelled out, resection and anastomosis was performed. Its content was a yellowish gray mushy material. Professor Stoerk found that the lining mucosa resembled that of the large intestine, and explained its origin as an embryonal inclusion of the entoderm.

Strode and Fennel (1923):[17] A male infant began to vomit on the second day after birth. Operation was undertaken on the fourth day for intestinal obstruction. About 6 cm. above the ileocecal junction, a cystic tumor 1.5 by 1.0 cm. was enucleated from the anterior surface of the ileum, but another larger cyst arising from the mesenteric aspect of the intestine just proximal to the first led to resection and anastomosis. The cysts presented a glairy mucinous content, a lining of low columnar epithelium thrown into papillary folds, stroma and muscularis mucosae. The larger cyst seemed to be situated in the subcumosa of the mesenteric aspect of the ileum; the smaller cyst was in the subserosa of the free portion of the ileum (opposite the mesenteric attachment). The baby died five hours after operation.

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11. Ball: Brit. J. Child. Dis. **2**:259, 1914.
12. Bolton, C., and Lawrence, T. W. P.: Brit. M. J. **2**:248 (Aug. 19) 1916.
13. Hanson: Hygiea **79**:1121, 1917.
14. Spencer, W. G., and Keith, A.: Brit. J. Surg. **8**:452 (April) 1921.
15. MacAuley, H. F.: Brit. J. Surg. **11**:122 (July) 1923.
16. Lotheisen, G.: Deutsch. Ztschr. f. Chir. **179**:394, 1923.
17. Strode, J. E., and Fennel, E. A.: Surg., Gynec. & Obst. **37**:781 (Dec.) 1923.

ORIGIN AND SITUATION

The origin of these cysts, called enterocystomas, has been ascribed by almost all writers on the subject to faulty involution of the omphalomesenteric duct. Early in fetal life, the entoderm of the primitive gut is continuous with that of the yolk sac. As development proceeds, this connection rapidly becomes constricted so that, in embryos of 5.0 mm., a very narrow channel exists between the gut and the interior of the

Fig. 3.—Section of cyst wall, showing its structure.

yolk sac. Normally, obliteration of this duct begins in embryos of from 7.0 to 7.5 mm. This is first seen at the intestinal end of the duct. In some instances, the involution is not begun until later, studies on embryos of 12.4 mm. and 13.6 mm. having been reported in which the duct is still patent throughout. The development of the intestinal tract in embryos from 10.0 to 40.0 mm. normally takes place in an umbilical hernia, the omphalomesenteric duct attachment demarcating the fore gut from the hind gut.

According to Meckel, an indication of its former connection with the yolk sac can be detected in the lower part of the small intestine in the third month of embryonic life. In about 2 per cent. of cases, a diverticulum ilei persists at this site. It is situated opposite the mesenteric attachment at a point from 0.5 to 1.0 meter proximal to the ileocecal valve; measures from 3.0 to 9.0 cm. in length, and may be attached to the mesentery or the umbilicus by its accompanying omphalomesenteric vessels, or obliterated structures corresponding to them. In some instances, only a fibrous strand remains, passing from the ileum to the umbilicus. Rarely, the whole duct is patent, and an intestinal fistula at the umbilicus results. In other instances, only the distal portion of the duct persists, and produces a cyst in the abdominal wall beneath the umbilicus. Colmers [18] collected four such cases.

It is reasonable to assume that a similar condition may exist at the proximal end of the duct, only a small part of it persisting. This, becoming closed off, would form a cyst in the wall of the gut. The difficulty lies in explaining the existence of cysts close to the ileocecal valve, and even in the cecal wall. Moreover, a considerable number of them are situated in the mesenteric part of the circumference of the ileum. Thus, of the enterocysts herewith reported, only three were in a position corresponding to that of Meckel's diverticulum, thirteen were in the terminal ileum, at or near the valve of Bauhin, and five were in the wall of the cecum. As far as could be determined from the descriptions, ten were situated in the free convexity of the bowel, and nine (possibly ten) were in the attached mesenteric part of its circumference.

In the literature, other cysts in the mesentery of the ileum, of varying size and at varying distances from the ileocecal valve, have been classified as enterocystomas. Although they had no demonstrable connection with the lumen or the wall of the bowel, they showed essentially the same structure as the intestinal cysts. Such instances have been reported by Kulenkampf,[19] Dittrich,[20] Studgaard,[21] Müller,[22] Hedinger,[23] Terrier and Lecene,[24] Puschmann [25] and others.

To explain the existence of these cysts, resembling the intestinal wall in structure but situated at points more or less remote from the site of Meckel's diverticulum, it has been stated that the latter structure

18. Colmers: Arch. f. klin. Chir. **79**:130, 1906.
19. Kulenkampf: Zentralbl. f. Chir., 1883, p. 679.
20. Dittrich: Ztschr. f. Heilk. **6**:277, 1885.
21. Studgaard: Zentralbl. f. Chir., 1895, p. 403.
22. Müller: Zentralbl. f. Chir., 1898, p. 147.
23. Hedinger: Virchows Arch. f. path. Anat. **167**:29, 1902.
24. Terrier and Lecene: Rev. de Chir., 1904, p. 161.
25. Puschmann: Ztschr. f. Chir. **72**:109, 1904.

may occur in any part of the terminal ileum, and may arise from its concave mesenteric border. The evidence for these statements is not so complete as one might wish. In Roth's [26] first case, a cyst was attached by a narrow communicating pedicle to the free convex border of the ileum at a point 66 cm. above the valve of Bauhin, undoubtedly arising in connection with Meckel's diverticulum. In his second case, a long

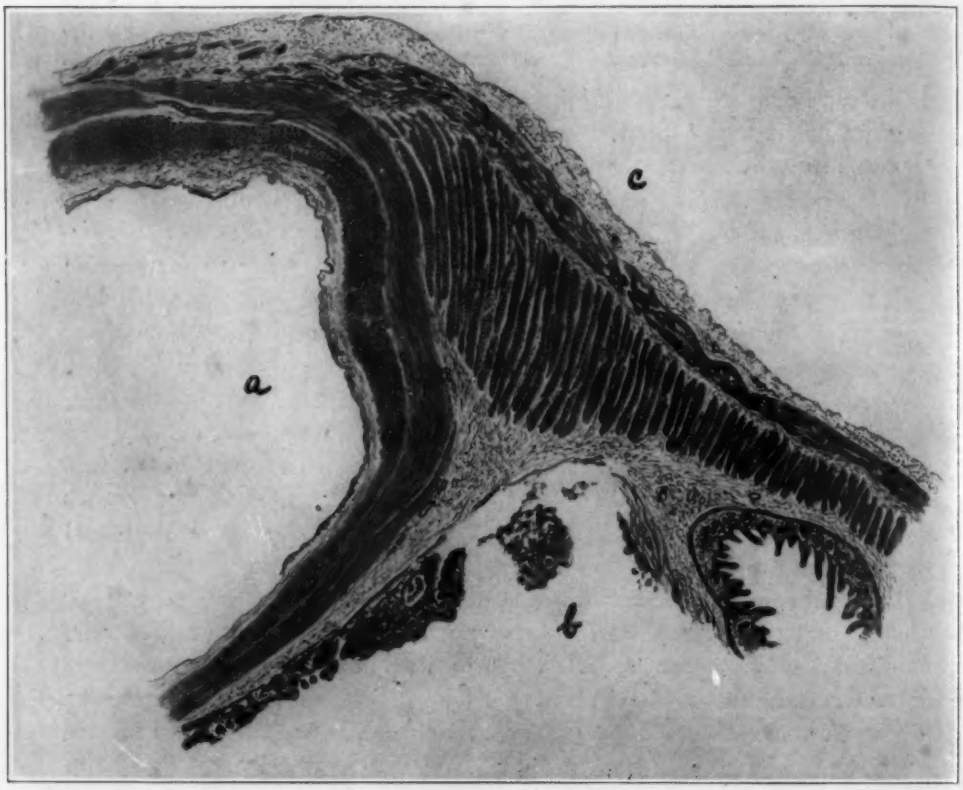

Fig. 4.—Section of intestinal and cyst walls at their fusion (low power); mucosa of cyst not well preserved: *a*, interior of cyst; *b*, lumen of ileum; *c*, serosal aspect of ileum.

sausage shaped cyst lay between the leaves of the mesentery and communicated with the lumen of the iluem. Two smaller cysts of similar structure did not so communicate, and a fourth was found in the posterior mediastinum. In Buchwald's [27] case, a large bilocular cyst in the mesentery communicated with the bowel.

26. Roth: Virchows Arch. f. path. Anat. **86**:371, 1881.
27. Buchwald: Deutsch. med. Wchnschr. **13**:868, 1887.

Other theories of the origin of these cysts have been advanced. Sainsbury [2] believed that in his case an invagination of the peritoneum in the formation of the ileocecal valve was responsible. Ayer,[8] Turner and Tipping [9] and Keith [14] believed that the cysts were formed primarily in the mesentery and, as development proceeded, they became incorporated secondarily in the wall of the intestine. Lotheisen [16] and Stoerk, and Strode and Fennel [17] believed that early entodermal inclusions in the wall of the gut offered a simple explanation. Müller [22] spoke of a snaring off of the gut as the cause. Roth,[26] Niosi [28] and Colmers,[18] among others, ascribed all intraabdominal cysts resembling the intestinal wall in structure to anomalies in the development of the omphalomesenteric duct. Colmers,[18] in his analysis of thirty-nine enterocystomas, made the following classification: (1) those situated in the abdominal wall (four cases); (2) those arising from the free convexity of the bowel (twenty cases); (3) those situated in the mesentery (fifteen cases).

It is my belief that the conclusive proof of this theory must await more extensive observations on the variations in situation and development of the omphalomesenteric duct in human embryos.

CLINICAL MANIFESTATIONS

In some instances the cysts were accidental findings at necropsy, as in the case in an infant of 10 days dying of gastro-enteritis, and in another of 4 months dying of pneumonia. One child of 11 years died of typhoid fever, with no history of symptoms referable to the cyst. It was situated in the cecal wall but did not encroach on the ileocecal valve.

Most of the enterocystomas in the ileocecal region give rise to obstructive symptoms early in infancy. There may be a preceding history of occasional mild attacks of vomiting and constipation, or merely unusual difficulty in feeding. The obstruction may be due to obturation of the lumen of the ileum, or of the ileocecal valve. A cyst in the cecal wall opposite the valve may occlude the orifice. No doubt the cysts are small at first and cause no mechanical interference, but as the mucous secretions accumulate, they become larger and produce such effects. In one infant of 6 months, the cyst was the cause of an intussusception.

Of considerable interest are the cases of older children and young adults with a history of recurring mild attacks of obstruction extending over a period of years before surgical intervention became necessary. In Sprengel's [5] case, a girl of 15 had had such attacks since the age of 4. An invagination of the cecum and lower ileum finally produced urgent symptoms. In Gfeller's [6] case a girl of 11 with symptoms dating from the

28. Niosi: Virchows Arch. f. path. Anat. **190**:217, 1907.

fifth year, developed a volvulus of the cyst-bearing loop, necessitating operation. In one of Quensel's [4] cases, a woman of 62 had a volvulus of the cyst-bearing loop with a sarcoma arising in its wall. Two young adults, 23 and 21 years of age, had attacks simulating recurring appendicitis for one and seven years, respectively. In nearly all of this group, a mass was palpable in the right iliac fossa.

The effects of the reported types of enterocystomas, including the mesenteric varieties, are: (1) no effects; (2) dystocia (in the case of large mesenteric cysts of infants); (3) torsion of the pedicle; (4) intussusception; (5) volvulus; (6) obturation ileus; (7) angulation ileus, and (8) new growths.

TREATMENT AND RESULTS

The treatment of enterocystomas causing symptoms is surgical. The following procedures have been employed: (1) primary intestinal resection; (2) two-stage operations for resection; (3) enucleation, and (4) marsupialization, *a*, external, *b*, internal.

Of the cases herewith abstracted, operation was performed in twelve. Primary resection and anastomosis was performed in seven cases. Of four infants, three died. In the fourth, Ball's case, an ileostomy was also established, and the child finally recovered. Of the three adult patients, Sprengel's [5] and Lotheisen's [16] got well. Two stage resections were attempted in two infants, but failed. One cyst, in Gfeller's [6] case, was successfully enucleated. Turner and Tipping [9] performed an external marsupialization, which was eventually successful.

The simplest and most rational procedure was employed by Ayer,[8] who opened the bowel, removed the cyst wall presenting interiorly and, by whipping over the cut edge of cyst and intestinal wall, effected an internal marsupialization. This should be the operation of choice.